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From: Peggy Lambert, ONR 93
To: Bill Nesselt, CNO N2K

Subj: DECLASSIFICATION

Ref: (a) Your fax to Tina Parker, ONR, of 20 Jun 97

1. Reference (a) requested assistance in determining current classification of National Research Council, Committee on Amphibious Operations, report "Underwater Swimmers" dated November 1952 (AD 311-923).

2. The report was declassified by Office of Naval Research letter of 3 July 1972. It should be marked "Distribution Statement A: Approved for Public Release; Distribution is Unlimited."

3. Questions may be directed to me on (703) 696-4619.

Peggy Lambert

PEGGY LAMBERT
ONR SECURITY MANAGER

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NATIONAL RESEARCH COUNCIL — COMMITTEE ON AMPHIBIOUS OPERATIONS

(1)

311923

UNDERWATER SWIMMERS

311923

Prepared for the

OFFICE OF NAVAL RESEARCH

by the

PANEL ON UNDERWATER SWIMMERS

November 1952
Washington, D. C.

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(6) UNDERWATER SWIMMERS [U]. - (8)

~~Prepared for the~~

~~Office of Naval Research~~

~~by the~~

~~Panel on Underwater Swimmers~~

(5) Committee on Amphibious Operations, NAS-NRC, Washington, D.C.

~~National Research Council~~

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ABSTRACT

A Panel on Underwater Swimmers was formed under the National Research Council Committee on Amphibious Operations. It is composed of civilian members representing the several major technical areas of interest in underwater swimming, and military officer and civilian associates. In addition to its own deliberations, the Panel sponsored staff studies, a symposium, and a field research project in preparation for this report. Following a discussion of the unique abilities and limitations of underwater man are the general conclusions and recommendations of the Panel. The Panel concludes that man can operate safely and efficiently underwater if properly equipped with adequate self-contained underwater breathing apparatus and suits, is aided in propelling himself by means of small submerged craft or individual propulsion units; and is to some degree protected from underwater blast. The report emphasizes the ability of underwater swimmers to operate while maintaining tactical surprise. The Panel feels that the full potential of underwater swimmers for offensive use against shipping and harbors has not ~~yet~~ been realized~~, nor is our present knowledge with respect to countermeasures adequate~~. The main body of the report contains descriptions of the state of knowledge with respect to the several phases of underwater swimming, statements of performance requirements for items of equipment, and recommendations for research and development needed ~~in order to be able~~ to achieve maximum underwater effectiveness.

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This report is ANNEX VIII reprinted from the Final Report of the Committee on Amphibious Operations, National Research Council, Washington, D. C., NRC:CAO:0031, November 1952. It is one of a series of reports prepared for the Office of Naval Research by technical advisory panels of the Committee on Amphibious Operations, National Research Council.

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Panel on Underwater Swimmers

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PREFACE

Underwater swimming was first looked at strictly from the Amphibious Operations standpoint. It quickly became apparent that the Amphibious Forces Underwater Demolition Teams had much in common with other military and civilian activities -- namely that of underwater swimming. While the applications and the tactics of the several underwater groups vary, all have common physiological and technical problems, hence the title of the report is the broad one of "Underwater Swimmers." Because of these many applications and varied technical problems, this report is a group effort. The group is officially known as the Panel on Underwater Swimmers of the Committee on Amphibious Operations. The panel is composed of members, associate members, and consultants, representing operational and technical areas both within and without the military establishment.

The persons contributing to this report are as follows:

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UNDERWATER SWIMMERS

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An initial activity of the group contributing to this report was the Symposium on Underwater Swimmers, held in Coronado, California, in December 1951. This was the first large gathering in the United States of technical and operational persons interested in the field of underwater swimmers. It was clear from that meeting that only a portion of the potential abilities of underwater swimmers for both military and civilian purposes had been exploited to date. It was also clear that scientists and technical men working in conjunction with operating personnel have many serious problems before them. Following the symposium, staff studies, meetings, discussions, and preliminary papers were sponsored by the Panel with the view in mind of contributing to this report. In addition, an ad hoc field-laboratory experimental group was sponsored during the summer of 1952 to more clearly formulate some of the basic problems in this field and suggest ways and means toward their solution. Because of the relative newness of this field, even the group experience of these technical and tactical people jointly writing this report might be considered a major step forward.

This report attempts to present the present "state of the art" of underwater swimming. It further attempts to point out the future potentialities, both military and civil for underwater man. Probably the most important single question it attempts to answer is, what are the unique capabilities of an Underwater Swimmer? It is hoped that this report will serve as a guide and a source of authoritative information for those in the field. Most important, perhaps, are the recommendations for research and development that must be undertaken so as to realize the full potential of this important military weapon and civilian research tool.

While the product of the group, the responsibility for the contents of the report lies with the civilian members of the Panel on Underwater Swimmers.

The panel wishes to express its thanks to Dr. Revelle and to W. A. Hahn for the final editing of the report, and to Midge Kolesar, and Mavis Merrill and the Committee on Amphibious Operation's Staff for the preparation of the manuscript and final copy.

3 November 1952 — The Panel on Underwater Swimmers

[redacted]

UNDERWATER SWIMMERS

by
The Panel on Underwater Swimmers
Roger Revelle, Chairman

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* The security classification of the material in this annex on Underwater Swimmers is no higher than Confidential. Also included in this annex is material from unclassified documents which retains its original classification and is not to be considered as upgraded by inclusion in this report.

UNDERWATER SWIMMERS

0 INTRODUCTION

This report is concerned with underwater swimmers. It is not limited ty specific type of swimmer, such as an underwater demolition man, or an osive ordnance disposal man, or a bottom scratcher. We are concerned ewhat with skin divers but mainly with underwater swimmers wearing self ained underwater breathing apparatus (SCUBA). For purposes of this re- an underwater swimmer is considered as a man underwater with no attach- s to the surface such as a telephone line or air hose. It is in this respect ly that he differs from the shallow water and deep sea diver.

History and legend are replete with stories of the exploits of individual mers both on the surface, and, in some cases, under it. The pearl divers shell divers of the Melanesian and Micronesian islands, the famed Japanese l divers and the Mexican stone divers, with practically no equipment, or at of the crudest kind, perform feats that western man has yet to achieve.

They explore the depths of the sea for food or for profit and perhaps for But western man, unlike his eastern cousins, has extended his underwater ies mostly for military purposes. Characteristically, a have-not nation Italy, in June of 1940, in the early part of World War II, led the way in the f swimmers as a very powerful modern military weapon. One of their first essful attacks was against the British cruiser YORK, a 10,000 ton ship which sunk in Suda Bay, Crete, along with three other ships. The Italians later ded their activities to include limpet swimmers, the use of motor torpedo , and the deadly two-man torpedoes. In two years, their effort resulted in 152 tons of shipping sunk or severely damaged -- a total of 31 ships. The e cost to the Italians for this impressive dent in the allied naval force was ingly low; 100 men, 20 of whom became casualties, and 50 prisoners, 17 or boats, 20 torpedo boats, and approximately 100 limpets.

The British were dismayed to watch their proud ships sink in the muddy s of Alexandria and Malta but they soon adopted this obviously good idea of alians for their own purposes. They directly copied, improved, and added equipments for the underwater activities of their swimmers. One of their famous exploits with their "X craft", as they named their midget submer- s, was the damaging of the German battle cruiser TIRPITZ, September 1943, Norwegian fjord. Of notable importance during World War II were the fam- ritish "P" Parties which explored harbor bottoms, quays, locks, etc., for em obstacles and booby traps, and cleared newly captured harbors. The h also formed small Landing Craft Obstacle Clearance Units which took n the initial phases of the Normandy landings, simultaneously with, and t without awareness of, the Italian activities. The Office of Strategic ces formed and trained groups of men for underwater attacks on shipping,

beach reconnaissance and demolitions, and the landing of agents by sea. Some of these men were absorbed in the formation of U.S. Navy Underwater Demolition Teams, while others were assigned to work with the British in England and Burma.

The first U. S. teams of swimmers worked with the British at the Normandy landings and suffered up to 45% casualties. Among the principal reasons for these high casualty rates was the lack of naval gunfire support. The swimmer parties were subjected to severe fire from the beach and to some extent from aircraft above. The Underwater Demolition Teams of the United States Navy, as we know them today, first saw action in the Pacific operations. These men were trained initially at Fort Pierce, Fla. and later on the island of Maui, T. H. In the Pacific they performed the reconnaissance demolition operations which are still a basic pattern in amphibious landings today. These teams are an integral part of the U. S. amphibious forces. We shall see later that tactics and equipment are substantially those developed during World War II.

Since the war, interest has been growing in sport fishing and in the sightseeing aspects of underwater swimming. In Italy and France, and more recently in the United States, especially on the West Coast, the sale of fins, masks, spear-guns, and the formation of underwater swimmer clubs has grown evermore rapidly.

Underwater swimming is now becoming an oceanographic research tool. Self contained underwater breathing apparatus is being increasingly used by archeologists, marine biologists, oceanographers, and others who want to go down into the shallow waters of the sea for a first-hand look at its many mysteries.

What are the unique characteristics of man under water, both in the military sense and for civilian uses? What are the limitations of underwater man, either alone or aided by equipment? What is it that underwater swimmers can do better than can be done in other ways?

A list of the unique capabilities of underwater swimmers would certainly include the following:

1. Intelligence, personal observation, judgment, direct action in the underwater environment -- in short, the personal touch.

2. Ability to coordinate underwater use of the senses of sight, hearing and touch.

3. Ability to operate with almost complete secrecy -- swimmers are nearly invisible from above the surface, noise output is low and there is little other detectable signal.

4. Ability to operate near a target -- "the hand placed charge" concept.

5. Flexibility. Swimmer units can vary in size from one man to several

underwater demolition teams, as we now know them; units can be made up for specific tasks from basic elements skilled in the fundamentals of underwater swimming; such forces are mobile and relatively self-sufficient.

6. Ability to operate in shallow water, narrow channels, and places where most other units can not. The underwater swimmer does not disturb the bottom nor need surface attendance.

What are the limitations of underwater men? With sufficient equipment there are few absolute limits, but the increased ability given by equipment must be weighed against the loss of unique capabilities which may result from its use.

At present time underwater men are:

1. Limited in depth of operation -- unaided skin divers can go to about 50 feet; self-contained underwater breathing apparatus (SCUBA) permits operations to over 200 feet (decompression required for over 130' when using air).

2. Limited in time submerged -- skin divers to about 2 minutes, SCUBA swimmers from two to about four hours.

3. Limited in speed -- unaided swimmers to about one knot; development of individual propulsive equipment might give about four knots; with midget craft five to fifteen knots seems possible.

4. Limited in ability to navigate -- development of ance systems may, however, make possible accurate navigation of underwater men over ranges of several thousand yards from a control station.

5. Limited in ability to see -- in turbid water to about three feet, in clear water 80 to 100 feet. With sonar, some perception may be possible at ranges from hundreds to thousands of yards.

6. Limited in power available -- 0.3 to 0.6 horsepower for continuous operation. 1.3 horsepower for a few seconds.

7. Limited in load carrying ability -- 5 to 7 pound pull.

8. Limited in temperature tolerance - 60°F. to 96°F. without protection.

9. Limited in range of operation -- unaided swimmers using SCUBA have a radius of underwater operation of about two miles.

10. Limited in maneuverability -- viscosity of the water environment prevents quick movements.

11. Vulnerable to explosives and possibly to other countermeasures.

UNDERWATER SWIMMERS

12. Limited psychologically by the unfamiliar environment, particularly at night.

From the above, it appears that the jobs that can probably be performed with the techniques of underwater swimmers better than by other means are:

1. Reconnaissance of underwater and near water areas with minimum risk of detection using visual, photographic, TV, and recording; landing of agents and other methods for gathering intelligence.

2. Hand-placing of demolition charges with minimum risk of detection prior to explosion. Removal of beach obstacles and natural barriers to landing areas, sabotage to enemy installations in or near water areas.

3. Mine detection, location and identification in areas where other mine-hunting means are ineffective.

4. Penetration of enemy held harbors, rivers and anchorages to conduct anti-shipping raids. This can be thought of as a relatively safe and cheap extension of submarine activities in areas where it is difficult for submarines to go.

5. Inspection of ships, locks, wharves, etc. for enemy activity, and similar harbor defense tasks, including active countermeasures against enemy swimmers and midget submersibles.

6. General utility, such as salvage, minor repair, emergency construction of bridges and wharves, deep fording of rivers and lakes, loading and unloading of sea-discharged vehicles.

7. Explosive ordnance disposal where conventional diving gear is relatively ineffective or cannot be used, that is in rough weather or areas of strong currents, where secrecy is desired, or where one does not want to stir up the bottom.

8. Service as an "aggressor force" to test countermeasure abilities.

Added to this list are scientific and recreational uses.

9. As a research tool for shallow water oceanographic studies, and in submarine archeology.

10. Underwater fishing and sightseeing. The rapid development of civilian interest in this field may prove to be of considerable military importance, not only because the development of equipment will be accelerated but because a reservoir of trained men will become available. Many of these may form a reserve for our forces; unfortunately some of them might prove in a crisis to be fifth column saboteurs.

No existing swimmer group can execute all of the operations listed above.

UNDERWATER SWIMMERS

Existing operational concepts and doctrines for swimmer groups are not clearly defined at present but in general, the missions of the several groups are as follows:

Underwater Demolition Teams. These are an integral part of the Amphibious Forces of the Navy. The principal job of the Navy's "Frogmen" is reconnaissance and demolition, prior to an amphibious operation, of those underwater man-made obstacles, natural obstacles, and mines, which are located between the three fathom line and the high water mark. Other specified missions of the UDT are to act as guides for the assault waves and to furnish further underwater reconnaissance and demolition after the assault waves have hit the beach. In addition to these missions, Korean experience indicates that UDT's may be called upon to perform various salvage missions, advance inland to blow up tunnels and to spot moored mines. In the main, these activities are carried out by skin diving techniques but each team has now formed a submerged operations platoon and the possibilities of completely submerged operations through the use of self-contained underwater breathing apparatus are being explored. Underwater Demolition Teams, because of their basic training in the use of explosives and in swimming, are potentially capable of many other operational tasks. Such tasks might include; sabotage, anti-shipping raids, limpet attacks, harbor penetrations, and the like. At the present time there are five Underwater Demolition Teams in the Navy (three Pacific, two Atlantic). The war complement of a team is 13 officers and 100 men.

Explosive Ordnance D[illegible] mission of the Explosive Ordnance Disposal Unit is to render s[illegible] dispose of, mines, torpedoes, bombs, and other explosives. Next [illegible] rendering safe explosives that cannot be detonated in place, the big[illegible]d by EOD personnel is to find the mine or other ordnance. Employ[illegible] swimmers for underwater ordnance disposal is a standard techniqu[illegible]tish Navy and is being explored by United States Navy Explosive Ordn[illegible]posal Units. Free swimming techniques, with the use of self-contained un[illegible]er breathing apparatus, would greatly increase the mobility of these units and reduce the logistical problems imposed by the necessity of using deep sea diving equipment. Noise-free and non-magnetic swimmer equipment would be required for this purpose, together with navigation or guidance equipment for systematic searching of the bottom.

Marine Reconnaissance Team Swimmers. There are no organized swimming groups as such in the Marine Corps. The Marines view underwater swimming as a means to approach the land objective of their reconnaissance teams. Surreptitious surfaced approach to beaches is becoming increasingly more difficult, as tactical radar, which can spot a surfaced craft or man immediately, becomes more available to the enemy. In these circumstances submerged approach is the only means which can provide maximum surprise.

Army Engineer Swimmers. The port construction, bridge, amphibious support and combat engineering units of the Army Engineers, while not habitually required to perform underwater tasks, are occasionally called upon to do reconnaissance, pier placement, inspection or repair, and demolition of underwater obstacles.

Beach Jumpers. Diversionary efforts of all kinds are the primary purpose of these Naval units. They use swimming as one of many techniques in carrying out their objectives.

Research Swimmers. The French have pioneered in the use of underwater swimmers, equipped with self-contained breathing apparatus, for scientific exploration of the shallow depths of the sea down to 200-300 feet. They have obtained remarkable results, particularly in submarine archeology. In the United States, compressed air SCUBA are being used by oceanographic and other research laboratories to explore at first hand the subsurface ocean waters and the shallow sea bottom. Classes in underwater swimming techniques are taught at the Scripps Institution of Oceanography and in other laboratories to marine biologists, geologists and oceanographers.

Sport Swimming. France and Italy have been leaders in the numbers of sport swimmers operating in their shallow water areas and in publications devoted to these activities. But interest in spear fishing and underwater sightseeing is continually growing in the United States, as evidenced by the formation of many "bottom scratcher" clubs on the West Coast and by the publication of a magazine entitled the Skin Diver[16]. The French publish Neptunia [12], the Italians Mondo Subacqueo[11].

From a military point of view, the operational requirements for offensive use of underwater swimmers are contained in a single concept. Since it appears probable that U. S. forces will not have numerical superiority over potential enemy forces, the requirement for tactical surprise and secrecy of operations is growing ever-more important. Wherever there are rivers, harbors, shores, lakes, or other water accesses, the employment of underwater swimmers promises to be a useful technique for covert reconnaisance and for achieving surprise. If the basic problems of underwater swimming for this purpose are solved, the possibilities of extending underwater swimming operations in other military fields will be greatly enhanced. In addition to being a potent military weapon, the underwater swimmer is a relatively cheap one, both from the standpoint of capital investment and in operating cost. He is a particularly ideal weapon for use by a small navy against a large one -- the more so if the former country has virtually unlimited manpower. The problem of defense against underwater swimmers is the obvious converse of the offensive one. Many sneak attack exercises practiced by our Underwater Demolition Teams on alerted American anchorages have dramatically shown that our Navy is extremely vulnerable to an enemy attack by swimmers. No effective round the clock defense is known at present. In order to develop such defenses, greater emphasis on underwater swimmer research, development, and training is urgently needed.

Men without proper equipment and adequate training can achieve only a minor fraction of their potential effectiveness under water. Swimmers can be trained to swim more efficiently than they do now, but nothing can be done about the fact that the peak power output of man is limited to 1.3 horsepower for a period of only twenty seconds, and for continuous operation he can generate only 0.56 horsepower [25]. If the task to be accomplished requires more power, he must be supplied with suitable

equipment. If man is to operate in hot water, some means of keeping him cool must be provided to prevent heat exhaustion. If he is to swim in cold water, he must be kept warm. He must be protected from blast, abrasion, toxic waters, and other hazards.

Many improvements can be made in fins, masks, knives, shoes, gauges, watches and other personal equipment, but all of these are apt to turn out to be marginal in terms of overall improvement in efficiency. On the other hand, research in mixed gas breathing and the development of self-contained underwater breathing apparatus to be used at varying depths for long periods of time, development of suits that allow freedom of movement yet provide maximum protection from excessive cold or warmth, propulsion systems, means of protection from underwater blast, communications and navigation, are apt to radically increase man's ability to perform tasks under water.

In this report, an attempt has been made to do three things: 1) to describe the present state of the art and science of underwater swimming; 2) to state the requirements for equipment and techniques which would enable underwater swimmers to achieve improved operational potentialities; and 3) to suggest the research and development necessary in order to attain the desired equipment and techniques.

02.00 CONCLUSIONS AND RECOMMENDATIONS

All of the conclusions and recommendations with respect to underwater swimmers have been gathered together in this section. The first subdivision (02.01) contains General Conclusions with respect to the broader or most important aspects of underwater swimming. The second subdivision (02.02) contains General Recommendations of similar nature. At the end of each of the sections of the chapters that follow are the conclusions and recommendations concerning those sections. They are repeated in the third subdivision (02.03) of this section for the convenience of the reader.

02.01 General Conclusions

1. Underwater swimmers, with appropriate training and adequate equipment are uniquely qualified to perform many military and civilian operations. They are also subject to a number of fundamental limitations. From a military point of view, the unique operational advantage in the offensive use of underwater swimmers can be summarized in a single concept -- tactical surprise. In future amphibious operations tactical surprise will be essential; preliminary reconnaissance may have to be conducted in complete secrecy. Underwater swimmers provide a means of accomplishing this.

2. Underwater swimmers can be a potent military weapon for harbor penetration and antishipping raids as has been demonstrated by the British and Italians during World War II and in recent U. S. [illegible] exercises. U. S. Forces do not currently have available the knowledge required for the full exploitation of the offensive potentialities of this weapons system, nor can they adequately defend harbors and anchored fleet elements against a group of determined swimmers.

Though current doctrine uses surface swimmers, it does not plan for the offensive use of underwater swimmers as described above, and only recently have small research efforts been initiated toward swimmer countermeasures.

3. Men without adequate equipment and training can achieve only a minor fraction of their potential effectiveness underwater. Equipment, training objectives and materials, safety rules and the like specifically designed for the underwater swimmer are urgently needed. The areas in which further technical knowledge and mechanization will yield the maximum increased performance and effectiveness are: closed and semi-closed circuit mixed gas self contained underwater breathing apparatus, swim suits for protection against cold water and underwater blast, swimmer propulsion units and submerged craft, secure communication and navigation systems, and the development of standardized safety and training procedures.

4. Specific quantitative information with respect to the abilities and limitation of underwater man is urgently required to provide adequate guidance for the detailed planning of future systems and techniques.

5. Although new tactics are continuously being developed by operational underwater swimmer groups, considerable technical work is in progress, and swimmer countermeasures are now beginning to be studied by some harbor defense agencies there is no single group that is specially charged with the responsibility for the continued development of underwater swimming techniques and equipment systems.

6. Because of the current and anticipated increase in research and development efforts on problems of underwater swimmers, the various items of underwater swimmer's equipment are progressing at different rates and with insufficient attention to mutual compatibility among the several components of the system.

7. There is no unified body of knowledge in existence relating to the many aspects of problems of underwater swimmers. Within the U. S. Military Services there are several centers of information relevant to this field. Knowledge on related technical subjects is spread throughout scientific and general literature of this country and abroad.

02.02 General Recommendations

1. The fullest exploitation of the unique potentialities of underwater swimmers for achieving tactical surprise should be made in future military planning and operations.

2. Research and development emphasis needs to be placed on projects directed towards maximizing this major advantage of using underwater men.

3. The above recommendations imply the development of means whereby underwater man's speed and endurance be increased and his liability to detection and countermeasure minimized. Emphasis should therefore be placed on:

a. Closed and semi-closed circuit mixed gas self contained underwater breathing apparatus

b. Swim suits for protection against cold water and underwater blast

c. Swimmer propulsion units and submerged craft

d. Secure communication and guidance systems

e. Development of standardized safety and training procedures

4. It is recommended that the responsible naval agency assemble all available records of actual and simulated shipping attacks and harbor penetrations performed by underwater and surface swimmers. It is expected that an analysis of these data will constitute forceful evidence of the usefulness of underwater swimmers in offensive operations and of the serious threat they pose to our defense.

5. So as to minimize delay in initiating vigorous and sufficient effort toward the technical and tactical development of offensive and defensive underwater swimmer techniques, it is recommended that the responsible naval agency stage a large scale realistically simulated underwater swimmers attack against a forewarned and defended harbor or fleet installation.

6. Experimental, analytical, and operations research techniques should be applied to underwater swimming operations in order to develop quantitative expressions of their abilities and limitations for use in future systems and operational planning.

7. There should be established within the military establishment a small group of operational and technical personnel charged with the responsibility for the continued development and test of new technical and operational ideas -- a technical and tactical inventions group. It should not be the task of this group to evaluate prototype production equipment, but rather to deal with items and procedures further in the future.

8. If such a group is established, it should have the additional function of serving as an underwater swimmer counterpart of the Army's "Agressor Forces" for the continued testing of the state of our swimmer countermeasures ability.

9. Effort needs to be directed toward coordinated planning and development of underwater swimmer systems and components. While the responsibility for this planning and development must remain within the military establishment one device that might be of assistance in accomplishing it would be the continuance of a Panel similar to the one responsible for this report. The Panel should be composed of civilian experts from the several [illegible] technical fields of interest, with the participation and advice of informed and interested associate members drawn from military research and operational activities. Associate members, while they may be official representatives of the agencies to which they belong,

should be at liberty to express unofficial opinions in the discussions of the Panel.

10. A central point of information exchange should be maintained for the compilation, receipt and dissemination of all operational and technical information relating to underwater man. An appropriate location for such an activity would be within the Office of Naval Research. One task of this activity might be the assembling of a selected and annotated bibliography of scientific and technical literature on underwater swimmers including a thorough search of the anthropological and sociological literature for information relating to the activities of native pearl and shell divers. Consistent with good security practices, this central information exchange activity should maintain contact with similar activities in U. S. civil affairs and foreign governments and groups. An Information Exchange Project (IEP) established with the United Kingdom, France, Italy and perhaps other countries for exchange of information on swimmer problems and advances might yield much valuable information in this relatively new field.

11. Within the limits of reasonable military security scientific and technical information should be treated on an unclassified basis in order to make the principles and technical advances in underwater equipment available to civilian (and contract) researchers and sport swimmers, so as to increase the fund of knowledge and experience in this country for the mutual benefit of all.

02.03 Summary of Specific Conclusions and Recommendations*

Physiological Problems

1. Continue field and laboratory study of significant physiological aspects of currently conceived underwater swimming activities. Those should include investigation of work rate, work efficiency, oxygen consumption and ventilation in order to facilitate design and evaluation of required breathing equipment. (03.00)

2. Advance and expand research on the altered dynamics of blood circulation during submergence, particularly as this applies to rapid changes in attitude underwater. (03.01)

3. Initiate study of physiological effects of prolonged breathing against abnormally high resistance, both inspiratory and expiratory. (03.01)

4. Continue study of the influence of nitrogen narcosis on human performance. (03.02)

5. Continue laboratory studies of oxygen breathing in man aimed at constructing useful tables relating duration of oxygen breathing to oxygen tolerance under various conditions of depth, work, inspired inert gases, inspired carbon dioxide, temperature and physical condition. (03.02)

* Numbers following the conclusion or recommendation refer to the sections of the report containing the supporting text.

6. Continue research in attempt to determine basic mechanism of oxygen poisoning. (03.02)

7. Initiate investigation of incidence and time of onset of oxygen poisoning at depths less than 60 feet, obtaining specific information concerning influence of small amounts of carbon dioxide, exertion, anxiety, cold and other significant factors. Study to include significance of so-called "mild" or "warning" symptoms. (03.02)

8. Initiate or continue research on specific medical problems arising in underwater swimming, i.e., prevention and management of fungus infection, treatment of contact with harmful animal and vegetable life, etc. (03.05)

9. Initiate study of decompression problems peculiar to underwater swimming, including methods of applying standard decompression tables to these activities, which often involve multiple changes in depth during a single dive. (03.02)

Selection and Training

10. There exists no formal body of knowledge on the art of underwater swimming, and standards of performance for underwater swimmers are unknown. As a result, the training of swimmers varies from place to place and from time to time, and the principles of selection of men for swimming tasks have only an empirical basis. (04.02)

11. Performance criteria for underwater swimming should be developed. (04.02)

12. After these criteria are developed, a series of qualifications for different levels of underwater swimming ability should be established. (04.02)

13. Only when it is clear what a swimmer can and should do, can standardized curricula be developed, instructors consistently indoctrinated, and adequate training material and facilities provided. (04.02)

14. Training facilities, texts, and material aids are inadequate. Studies should be initiated toward designing and developing standardized training procedures tailored to the particular needs of underwater swimmers. (04.02)

15. Further study should be given the questions of the best location for efficient and safe training of underwater swimmers, and whether swimming should be taught separately from the specific skills needed for reconnaissance, demolition, ordnance disposal, submerged attacks on shipping, and other missions. (04.02;04.03)

Effects of Underwater Blast

16. Underwater blast injury constitutes a serious potential hazard to underwater swimmers. In deep isothermal water there is danger of injury from a 1 pound

charge at distances less than 65 feet, and at less than 300 feet from a 100 pound charge. Safe distances for large charges are uncertain, because it is not known whether peak blast pressure or total impulse from the explosion determines injury. Research should be continued on the basic mechanisms of underwater blast injury.

17. Explosions are likely to be included in enemy countermeasures and these may nullify or deter our underwater swimmer operations. (05.00)

18. Protective clothing containing air or other sound-reflecting material might appreciably lessen the distance at which an explosive charge of given size is a serious hazard to a swimmer. (05.00; 06.03; 06.04)

19. Research and development on methods for protection of swimmers against blast injury are urgently needed. (05.00)

20. Reliable experimental data should be obtained on deterrent and lethal distances from explosive charges of different size. Until more such data are available, calculations for safe distances from known charges should be considered tentative. (05.00)

Suits

21. None of the existing suits in use or in the process of development appears to be completely satisfactory for protection against cold water. The "wet" suit offers great promise for development into a satisfactory cold water suit. (06.02; 06.03; 06.04)

22. Study of optimum design and materials for "wet" suits should be undertaken. The only work done with "wet" suits under the cognizance of the Panel has been to confirm the principle of the suit. The problem of designing a "wet" suit must thus start approximately from scratch. Certain features of the experimental suits may be useful in designing an operational garment: 1) the extensive use of (non-watertight) zippers, laces, or snaps, to produce a snug fitting suit which can be donned by the individual swimmer; and 2) the use of a tough foamed neoprene, with a strong mesh which allows the suit to stretch in all directions and yet is rigid enough to prevent excessive buoyancy change. (06.03; 06.04)

23. Development of improved designs for dry suits should be continued: 1) the fit of current issue U. S. N. two-zipper suits needs to be revised with respect to such things as calf and thigh size, zipper length, fit around face, and number of suit sizes available; 2) efforts to improve the watertightness of zippers should be encouraged; 3) until watertight zippers can be guaranteed, a dry suit without zippers such as the Pirelli or Dumas should be used; 4) the possibility of avoiding suit squeeze in deep operations should be appraised. The Cousteau suit with automatic internal pressurization may have useful features in this regard; and 5) the Dumas French suits are reccommended as a guide toward the development of an efficient dry suit. (06.02)

24. Investigation should be continued on the physiological and human

engineering aspects of protective clothing and related subjects.(06.03)

Self Contained Underwater Breathing Apparatus

25. No present type of SCUBA is adequate for all types of underwater operation. Fundamental research in the physiology of breathing under pressure, and development of improved equipment with wider flexibility and greater endurance is needed. (07.04; 07.06)

26. Open circuit, closed circuit and semi-closed circuit types of SCUBA each have distinct advantages and disadvantages. Each type is best adapted to aid in accomplishing certain underwater swimmer's missions, and the decision as to which should be employed must usually rest on the Field Commander, based on actual operational possibilities. (07.03)

27. Maximum security and/or the need for continuous underwater operation over a relatively long period will in many cases require that a closed or semi-closed circuit type SCUBA be employed. But for many operations requiring use of SCUBA, the simpler open circuit equipment can be employed. (07.05)

28. Efforts should be directed toward intensified study and development of carbon dioxide absorbent materials, and of substances which both absorb carbon dioxide and release oxygen (e.g., high oxides of potassium and the chelates) for use in closed circuit oxygen and mixed gas SCUBA. Correlation of research now in progress by government and civilian agencies to determine applicability to SCUBA should be continued. (07.07)

29. There should be continuance of development of SCUBA from operational, safety and physiological viewpoints, aiming at increased security, work capacity and submerged operating time of the equipment commensurate with man's bodily endurance and ability to do useful work. Improvement of open circuit, closed circuit and semi-closed circuit apparatus to achieve: 1) lower breathing resistance; 2) increased gas economy (in open and semi-closed circuit types), 3) more effective carbon dioxide absorption (in closed and semi-closed types); 4) streamline form; 5) simplicity and reliability of operation; 6) simplicity of maintenance; 7) maximum field of vision; 8) minimum magnetic signature; and 9) minimum sound output and echo target strength. (03.00; 04.03; 07.07)

30. Competition in SCUBA development and production is constantly growing, stimulated by increasing military requirements and public interest. This healthy commercial situation should bring more and better models into existence, provide new principles of operation and insure safer and easier operation.(07.04)

31. Investigation of the feasibility of a safe closed circuit mixed gas SCUBA should be continued. (07.06)

32. Continued study is required of quantitative laboratory and field methods of testing breathing apparatus with the purpose of improving validity of tests and obtaining basic information of value in improving design. (07.07)

33. Factors responsible for resistance to respiration in SCUBA and means of minimizing them should continue to be studied. (03.03; 07.07)

Communications

34. A satisfactory means of underwater sound communications among swimmers, submarines and large surface craft utilizing underwater sound has been developed and is believed ready for naval procurement. Underwater sound communications equipment for use between swimmers and small surface craft is about to be evaluated and should be ready for procurement shortly. While this is a big advance, underwater sound is not necessarily secure, so efforts must continue toward developing a secure underwater communication (and navigation) system. (08.00; 16.00)

35. Underwater Electric Potential (UEP) and direct wire methods should be further investigated as alternate means of underwater communications because of their greater security as compared to sonar. (08.00; 16.00)

Navigation

36. Electronic aids to navigation may prove useful in types of swimmer operations where secrecy is not paramount, or where a calculated risk of detection can be taken. (09.00)

37. Promising results have been obtained in preliminary trials of both guidance beams and two-way communication systems for underwater navigation as well as with infrared equipment for use above water. (09.00)

38. Because use of electronic aids to navigation will inevitably diminish the secrecy with which underwater operations can be conducted, further development should be guided by an operational analysis of the navigational and other requirements of the several applications of swimmers. (09.00)

39. The difficulties of underwater navigation resulting from the absence of land marks, the short range of visibility and the marked effect of currents on the position of a slow moving object may well prove to be the limiting factor in underwater swimmer operations. Unique and ingenious methods of what might be called "passive" navigation are therefore required. (09.00)

Underwater Photography and Television

40. Underwater cameras and accessory equipment are not readily available in this country for scientific or military use by underwater swimmers and those units that are available are very expensive. (10.03)

41. Equipment which is available in most cases has been designed for other types of diving and is not, in general, applicable fo. [illegible] ational use by underwater swimmers. (10.03)

42. Exchange of information with French and other foreign underwater swimmers and photographers should greatly aid development of adequate United States photographic equipment for military and scientific uses. (10.03)

43. Underwater television equipment manipulated by swimmers should prove useful for identification of mines and other submerged objects, for salvage operations and for inspection of underwater structure. The possibilities of electronically enhancing contrast suggest that underwater television may be made more effective than the human eye as a means of seeing underwater. (10.04)

Ships, Boats, and Craft

44. The limited range of unassisted swimmers, particularly if they must carry equipment or explosives, makes it necessary to transport them as near to the objective as possible. (11.01)

45. For present surface UDT operations where one or two teams of 113 officers and men each are employed, a somewhat larger and better fitted surface ship than the APD would be desirable. (11.02)

46. A better small surface craft than the LCP(R) is also required. It should have 15--20 knot speed, low silhouette, minimum bow wave and other features designed to meet the specific needs of Underwater Demolition Team swimmers. Development of lighter and more easily handled rubber rafts should also be continued. (11.03)

47. Whenever it is necessary to operate near an enemy held shore in as complete secrecy as possible, the approach to the objective must be made under water. The first part of the approach can be made in a fleet type submarine, but for the final approach, a small submersible to be carried and launched by the submarine is needed. For these submerged operations certain modifications of fleet type submarines are desirable to facilitate egress and re-entry of swimmers and for stowage and launching of small submersibles. (11.02)

48. The desirable characteristic of small underwater craft for underwater swimmers depend on the kinds of work the men are expected to do and the nature of the mother ship. In general, the boats should be quiet, have low sonar target strength and magnetic signature, be as nearly invisible as possible, and have adequate storage space, speed, endurance, and seaworthiness. (11.04)

49. Open and closed cockpit, small submersibles each have advantages and disadvantages which fit them for different types of underwater missions. Models of both open and closed cockpit small submersibles should be designed and built for experimental use by United States underwater swimmers, in order to fully develop the operational possibilities and requirements of these craft. Because of the small number of men who can be transported in a small submersible, the general use of these craft may markedly alter the doctrine and tactics of UDT's. (11.04)

50. In the design of small submersibles, problems of stowage and launching

from a moving submarine must be taken into account as well as the need for adequate speed to overcome currents and to allow evasive tactics, endurance, ease of egress and re-entry, safety and comfort of the crew, and minimum detectability. (11.04)

51. Man's efficiency as a swimmer is very low; that is, only a small part of the energy he expends in swimming is effective for propulsion. An "underwater bicycle" is needed which would either be mechanically powered or would link the swimmer's muscles to the water in a more efficient manner. Development of means of propulsion for individual underwater swimmers should be vigorously pursued. (03.04; 11.05)

Underwater Object Location

52. In the development of mine hunting equipment, advantage should be taken of the ability of underwater swimmers to carry and direct detecting and identifying devices close to mines and other obstacles. (12.00)

Buoys

53. Buoys are an important item of an underwater swimmer's equipment because they translate his detailed knowledge of underwater conditions into terms suitable for surface forces. It is conceivable that the success of a large operation might hinge on the successful use of buoys by underwater swimmers. Present simple buoys for daytime use are reasonably satisfactory but there is need for lighted, depth-taking, time-delay, "complex" buoys and their associated anchors. (13.00)

54. Development of complex buoys, preferably tailor-made for specific types of operations, should be continued. Use of new materials such as plastic foam, self-sealing bags, washtub concrete, honeycomb, reflector surfaces, fluorescent paint and nylon line, etc., should be investigated in this development. (13.00)

Demolition and Ordnance Equipment

55. Demolition explosives for UDT use under current doctrine are satisfactory and means of submerged towing of explosive charges are under test. (14.00)

56. World War II U. S. and foreign limpet and sneak attack ordnance designs are available. As sneak attack and antishipping techniques are developed it will be necessary to concurrently develop the required demolition and ordnance equipment (01.00; 14.00)

Miscellaneous Equipment

57. Face masks, life preservers, swim fins, depth gauges and knives now used by underwater swimmers, or becoming available to them, are reasonably satisfactory. Some improvements or changes may be desirable. The field of

vision through masks needs to be widened; life preservers might profitably be integrated with SCUBA; swim fins with soft, pliable rubber around the foot, becoming less compliant toward the tip, might result in increased swimming efficiency. The depth range and night readability of depth gauges could be improved; and a new knife now in the preliminary design stage appears superior to the type currently used. (15.01; 15.02; 15.04; 15.06; 15.07)

58. Watches, compasses, and bottom surveying equipment need considerable improvement. Most present swimmer watches leak when subjected to hydrostatic pressure. (15.03; 15.05; 15.08)

59. A small, sturdy, luminous-dial compass, operable to depths up to 200 feet and when inclined as much as 30°, and rigidly attached to the swimmer's face mask where he can watch it continuously when necessary, is needed to aid swimmer navigation. (15.05)

60. Development of self-recording devices for measuring bottom depth and distances would increase the speed and accuracy of swimmer reconnaissance. (15.08)

61. Both mechanical and acoustic methods of automatic bottom surveying should be investigated. (15.08)

62. Underwater swimmers change depth frequently and unexpectedly. An "analog computer" type of depth gauge which would simulate the interchange of inert gases between the blood and the tissues might greatly aid in controlling decompression to avoid the damage of bends and allow maximum time submerged. Research and development leading to an analog computer type of depth gauge should be initiated. (15.07)

63. Development of devices for measuring beach trafficability is not warranted because the sampling errors would be too large. Instead, UDT's should receive more training in estimating beach trafficability. (04.02; 15.09)

Countermeasures

64. Countermeasures against underwater swimmers have been practiced in simple form but U. S. forces do not have available the knowledge to mount a round-the-clock defense of harbors and anchored fleet elements against a group of determined swimmers. The need exists for intensified systematic research and development in this field.

03.00 PHYSIOLOGICAL PROBLEMS

Underwater swimming and diving with self contained underwater breathing apparatus (SCUBA) is subject to certain physiological limitations which vary in relative importance in different diving tasks and techniques. Most of these limitations are predictable and therefore avoidable when established restrictions are adhered to, and when diving education and training are adequate. Under these conditions, underwater swimming is a relatively safe operation. This is indicated by the rarity of serious accidents in UDT training programs and operational missions during and since World War II.

The major problems of self contained diving are essentially similar to those of deep sea diving. They are related to the physical effects of exposure to great changes in hydrostatic pressure, or to the physiological effects of respiratory gases under increased partial pressure and will be discussed under these headings. Another class of difficulties bears no distinct relation to diving depth and will be discussed separately. Considered in this category are troubles due to equipment failure, exposure to low or high water temperatures, physical exhaustion and dangers introduced by marine life.

03.01 Pressure Effects

Squeeze* - Squeeze may occur if a few simple precautions are not observed during descent. It is due to the effect of increasing external pressure upon the ears and sinuses, the face plate or the swim suit uncompensated by an equal increase in pressure from within. The incidence of squeeze is low. It is recognized by beginning pain in the ears and sinus areas, or by a feeling of tightness within the face covering, usually within the first few feet of descent. This pressure differential decreases with increased depth. Face squeeze can easily be prevented by exhaling into the face plate. Equalization of the internal ear pressure can be accomplished in several ways. The most effective method is to close the nose and mouth and force air into the back of the throat. Deliberate yawning may help if mouth piece is not being used. Preliminary inflation of the ears just before entering the water is very helpful and should be practiced routinely. The swimmer with an acute head cold or throat infection should not enter the water. If pain does occur at any depth the swimmer should ascend a few feet before again trying to readjust the internal pressure.

Serious consequences of squeeze are unlikely. Nosebleed, hemorrhage in the conjunctiva, sinuses or middle ear, and ruptured eardrums can occur if the symptoms are ignored and subsequent complications usually prevent swimming for a week or two.

Aeroembolism. If a man holds his breath during ascent the air in his lungs rapidly expands and, by overdistension, may tear the lung tissues allowing air

* This term is deliberately employed in a wider sense than usual to cover all instances of uncompensated pressure.

to be forced into his pulmonary blood vessels. This injury can occur on ascent from even shallow depths. The incidence is very low, particularly among well trained and experienced swimmers. In the extensive open sea self contained diving since World War II, no cases of aeroembolism are known to have occured. It can almost always be prevented by maintaining relaxed respiration upon ascent and avoiding breath holding. Because the disorder forces air bubbles into the blood stream it may be serious, resulting in convulsions, pain, paralysis, reflex spasms, or even death. Treatment involves immediate recompression in a pressure chamber. Relief of symptoms is to be expected, if the duration and severity of symptoms is not great.

03.02 Effects of Breathing Respiratory Gases Under Increased Pressure

Narcosis. Like most inert gases, nitrogen in air or N_2 - O_2 mixtures breathed at high ambient pressure can decrease mental clarity, impair judgment and produce poor muscle coordination in a manner similar to that found in alcohol intoxication. The narcotic effect is related to the partial pressure of inspired nitrogen; it is therefore a function of depth of diving and the percentage of nitrogen in the respired gas. Nitrogen narcosis is not in itself harmful, but when air (80% nitrogen) is breathed (as in open circuit equipment) at depths below about 60-80 feet the resulting impaired judgment and incoordination begins to interfere with performance and predispose to accident. The narcotic effects increase progressively with depth until at about 280-300 feet even routine tasks become extremely difficult. As in the drinking of alcohol, personality, motivation, and training in a specific task account for the different reactions among different men.

In orthodox deep sea diving narcosis can be reduced by substitution of helium for nitrogen. Unfortunately, on deep dives of short duration, typical of underwater swimming, the use of helium in place of nitrogen increases the decompression time required to avoid bends.

Decompression sickness or bends. Dissolved nitrogen in the blood and tissues is only slowly gained or lost by the body, and tends to remain in solution except during rapid changes from greater to lesser pressures. The dissolved nitrogen will come out of solution and form bubbles in the blood and other tissues in the same way that bubbles are formed in carbonated beverages when they are decompressed by removal of the cork. Nitrogen which comes out of solution under these conditions may form sufficiently large and numerous bubbles to cause obstruction to blood flow in small vessels, painful distention of tendons, joint tissues, muscles, old scars, fractures, etc. If the ascent is sufficiently slow the excess nitrogen will be harmlessly eliminated by the lungs and bends will not occur. For each depth down to 130 feet there is a diving duration which can be accomplished without need for decompression other than that accomplished by normal ascent rate. The danger of bends during decompression is increased by exposure to greater depths, by exposure over longer periods of time, and by too rapid ascent. There is little tendency for bends on dives less than [illegible], even while breathing air; if deeper diving is to be performed using air, slow and regulated ascent must be carried out. This requires the swimmer to have a portable gas supply which will

provide not only for the period of work at depth, but also for the period of slow decompression as he returns to the surface. Navy decompression tables should be strictly observed in regulating decompression. [4] Pain evoked by too rapid accent can be eliminated by redescent or recompression in a chamber if available. This increase in pressure will force the bubbles back into solution. If there are no lasting effects caused by the previous existence of the bubbles, and if subsequent return to the surface is graded properly recovery will be immediate and complete. It is interesting to note that the French have developed special underwater swimmer decompression tables, characterized mainly by "factors" for repetitive dives on the same day. [8] The validity of these has not yet been checked in this country but perhaps they might serve as a starting point for extension or specialization of Standard Tables to fit the specialized requirements of underwater swimmers.

An extension of diving depth and/or duration beyond that feasible with air can be accomplished by the use of other gas mixtures, in which the percentage of nitrogen is lower than in air to dilute the nitrogen inhaled. Much research is needed along these lines.

Fig. 1 Field research on problems of underwater swimmers is an unglamorous pursuit.

<u>Oxygen toxicity</u>. Pure oxygen cannot be breathed indefinitely at pressures greater than atmospheric. Following a safe period which becomes shorter as diving depth increases, symptoms of oxygen toxicity occur. These include involuntary fine twitches around the eyes and mouth that later extend to include larger muscle

groups including the diaphragm, causing abruptness of inspiration. Anxiety, and apprehension may occur and sometimes loss of lateral visual fields and ringing in ears. These preliminary symptoms are followed by general convulsions and unconsciousness. These can be avoided by not exceeding the safe depth-time relationships for pure oxygen breathing. The onset of oxygen poisoning can usually be arrested by inhaling a few breaths of a gas mixture with a high proportion of nitrogen or other inert gas. Permanent after effects from oxygen poisoning do not appear to occur, even after repeated exposures. This of course does not alter the risk for the underwater swimmer at depths great enough to produce toxicity.

The basic physiological mechanism of oxygen poisoning and the effects of oxygen at depths from 15 to 60 feet, and greater, are subjects that require much more study, since oxygen poisoning is the major factor limiting diving depth and duration with mixed gas as well as pure oxygen apparatus.

03.03 Equipment Failure

Respiratory blockage. The most obvious problem is severe interference with breathing from many factors. It should not occur in properly designed apparatus. If the swimmer is completely familiar with the equipment and does not panic, he will usually have time to initiate remedial measures or to surface if necessary.

Carbon dioxide excess. CO_2 excess is a possibility wherever carbon dioxide absorbing canisters are used or where, because apparatus design does not reduce apparatus deadspace, some carbon dioxide is re-inhaled. The chief symptoms, which furnish ample warning to trained men, are increased effort of breathing, a sense of breathlessness and headache. Unheeded warning may result in exhaustion and unconsciousness. The incidence is low. Assuming that the design of the apparatus is adequate for the purpose for which it is used, prevention is accomplished by using fresh soda lime with each dive, correct canister loading, and care in keeping the soda lime dry.

Anoxia. Anoxia can occur if large amounts of nitrogen are present in the rebreathing bags of closed or semi-closed circuit rebreathing apparatus and the oxygen supply fails or becomes exhausted. The onset of anoxia is frequently accompanied by a feeling of elation and well being which is so deceiving as to be difficult to recognize even by experienced swimmers. The man usually loses consciousness without warning. In pure oxygen rebreathing units, this can only occur through an error in the diver's technique (poor nitrogen elimination) and should be completely preventable by training. Where nitrogen is intentionally used in the breathing mixture, anoxia can result from mechanical failure of the apparatus or exhaustion of the gas supply.

03.04 Exhaustion

A limiting factor in the execution of a mission will frequently be excessive fatigue of the swimmer rather than any of the factors mentioned above. A man can

produce an output of roughly 0.3 to 0.6 horsepower for several hours, providing that he is comfortably warm, does not attempt work beyond his ability, and is not handicapped by respiratory fatigue due to resistance to breathing. Factors to be borne in mind when analyzing the causes of fatigue in swimmers follow.

Thermal exhaustion. The underwater swimmer is extremely sensitive to moderate changes in water temperature in both directions because water is a much better heat conductor than air. At present there is no equipment to protect a man against moderately warm water. Heat prostration may occur during exercise in water around 86°F. and at rest in water around 96°F

A much commoner stress is water colder than 65° to 72°F. Many types of clothing have been devised to protect against cold water. Unfortunately most have obvious handicaps such as loss of protection when wet inside, limitation of motion, squeeze and chafing at depths, marked buoyancy changes at depth and lack of a mechanism to rid oneself of sweat and excreta. It would seem imperative to look for a radical change in thinking about suit material. Recent preliminary studies with a wet foam plastic suit are most promising and encouraging. (06.04) More such studies are in order.

Work exhaustion. Often a man may need help either during or after a mission due to fatigue. Examples are inability to climb into a boat or raft, to enter a submarine after a mission or to remain afloat when surfaced. This suggests at least two precautions: 1) to have available non-fatigued associates at the end of a mission and 2) to have available an easily inflatable bladder or life jacket that will keep the swimmer comfortably afloat at rest.

Respiratory exhaustion. Resistance to underwater breathing has four components: 1) airway resistance caused by valves, length and diameter of tubing, and possibly inertial factors due to the density of the inspired gas at increased depth; 2) hydrostatic resistance caused by the difference in pressure between the level of the swimmer's center of breathing (most commonly believed to be at the bottom of his throat) and the level of the inlet or demand valve; 3) inertial resistance introduced by the inertia of water which must be displaced during respiratory movements of the chest; and 4) miscellaneous factors such as the resistance of breathing bag fabric to inflation and deflation.

03.05 Miscellaneous Problems

Otitis externa. Infections of the external ear canal may occur. The incidence of this disorder is fairly frequent. It is not serious but is incapacitating because the swimmer should not put his head underwater until the infection is completely healed. A few drops of an alcohol solution or other drying agent put in the ears after diving will help dry the canals and prevent infection.

Danger from marine animals. The underwater swimmer apparently has as much to fear from invertebrate animals such as bar[illegible], coral, jellyfish and sea urchins, as from vertebrates such as sharks, barracuda and seal, although Moray eels will bite severely if molested and rays will inflict a wound if stepped upon. The

invertebrates cause lacerations stings and punctures when the swimmer brushes against them. These wounds may become infected and usually prevent swimming until healed. The incidence is low if proper precautions are taken. Except perhaps for a very large jellyfish these injuries do not incapacitate a swimmer but a large concentration of jellyfish would constitute a serious operational hazard.

Dangers from marine flora. The swimmer should avoid becoming entangled in kelp or eelgrass. Generally the swimmer can "ease" his way out of kelp but the possibility of such entanglement serves to emphasize the need to carry a knife at all times and the importance of the buddy system in rendering assistance to the victim.

03.06 Avoidance of Underwater Swimming Hazards

Insofar as human factors are concerned, the best precautions against the dangers involved in diving are: proper selection of healthy, educated, intelligent men of stable character, proper training in accordance with the principles set forth herein, and intelligent adherence to established doctrine.

03.07 Conclusions and Recommendations

1. Continue field and laboratory study of significant physiological aspects of currently conceived underwater swimming activities. Those should include investigation of work rate, work efficiency, oxygen consumption and ventilation in order to facilitate design and evaluation of required breathing equipment.

2. Advance and expand research on the altered dynamics of blood circulation during submergence, particularly as this applies to rapid changes in attitude underwater.

3. Initiate study of physiological effects of prolonged breathing against abnormally high resistance, both inspiratory and expiratory.

4. Continue study of the influence of nitrogen narcosis on human performance.

5. Continue laboratory studies of oxygen breathing in man aimed at constructing useful tables relating duration of oxygen breathing to oxygen tolerance under various conditions of depth, work, inspired inert gases, inspired carbon dioxide, temperature and physical condition.

6. Continue research in attempt to determine basic mechanism of oxygen poisoning.

7. Initiate investigation of incidence and time of onset of oxygen poisoning at depths less than 60 feet, obtaining specific information concerning influence of small amounts of carbon dioxide, exertion, anxiety cold and other significant factors. Study to include significance of so-called "mild" or "warning" symptoms.

8. Initiate or continue research on specific medical problems arising in

underwater swimming, i.e., prevention and management of fungus infection, treatment of contact with harmful animal and vegetable life, etc.

9. Initiate study of decompression problems peculiar to underwater swimming, including methods of applying standard decompression tables to these activities, which often involve multiple changes in depth during a single dive.

04.00 SELECTION AND TRAINING

04.01 Selection

There are as yet no generally accepted principles to govern the physical and psychological selection of underwater swimmers. Since swimming demands a continued bodily exertion comparable to running, it is obvious that a candidate should be in a state of general good health and be in prime physical condition. Any history or evidence on complete physical examination of chronic respiratory or cardiovascular disorder should disqualify a person from this activity. Middle ear disease, exaggerated susceptibility to motion sickness, or inability to clear the ears is similarly disqualifying. Exaggerated vasomotor response to cold, or other manifestation of unusual sensitivity to cold water exposure also ought to be eliminative. Fear of the water, excessive fear of the dark, claustrophobia, general apprehensiveness or excitability, foolhardiness, or a tendency to take unconsidered risks -- should bar a man from underwater swimming.

At present, the Navy Underwater Demolition Teams accept only volunteers and consider this to be an essential factor in their success. UDT's must qualify in the standard physical examination for deep-sea divers. The early stages of their training are organized to screen out those men who are unable to take the rigors of difficult operations. The UDT volunteer undergoes a "Hell Week" when he is awakened at odd hours, takes long, forced swims, hikes and portages, during which explosives are frequently set off nearby. All candidates for UDT are exposed to pressure equivalent to a depth of 112 feet of water in a recompression chamber, and they must demonstrate an ability to equalize their ears to this pressure change; they are also tested for their oxygen tolerance, for which purpose they are kept at rest at a simulated depth of 60 feet for 30 minutes while breathing oxygen. Because the UDT men may be called upon to perform solitary and difficult missions in strange waters, the UDT applicant should have a mental ability at least on a par with that of submarine and diving personnel.

It is the experience of submarine medical officers that men with low alcohol tolerance, or small mental stature are especially susceptible to the drunkeness caused by high pressure nitrogen. The more mature, serious minded individual tries to overcome the effects of nitrogen under high pressure by determination and will, and can perform useful work at greater depths.

Good swimmers learn underwater techniques rapidly and ordinarily have a high degree of confidence in the water. At present it ... necessary that the underwater swimmer be able to swim long distances. Requirements demand an ability to swim 300 yards in less than 15 minutes using at least three standard

surface swimming strokes.

04.02 Training

The primary training objective in underwater swimming is to provide the swimmer with the necessary information, skill and experience to enable him to operate safely and efficiently in this new and unfamiliar environment to which he is not naturally adapted. Only after he has been thus trained can one profitably consider his further training for the several specific missions for which the underwater swimmer is uniquely qualified.

The would-be underwater man must first fulfill the selection requirements described above. After it has been determined that he is physically and mentally qualified to undertake underwater work he must demonstrate a reasonable swimming ability and begin training to perfect his swimming capacities. It is suggested that more attention be paid to swimming form, synchronized breathing, and perfected underwater propulsion techniques with an emphasis on maximum speed and endurance in the water. While mastering these skills, the underwater swimmer should learn the essentials of diving physiology. Existing documents and training films are adequate for teaching the essentials to future deep sea divers but new material should be prepared to meet the special needs of the free swimming underwater man.

The swimmer should be well indoctrinated in the use of the face mask, fins, and the techniques of skin diving. Particular attention should be paid to the prevention of air embolism, how to "pop" the ears, hyperventilation and breath-holding for a relatively extended period. Having demonstrated confidence and skill in the water, the candidate may start learning the use of SCUBA. As in the basic steps, care must be taken to build up confidence, beginning with dry drills, runs in the comfort and safety of the swimming pool, and then in calm, clear, open sea areas, before going on to cold, rough, dark, and deep advanced operations. The swimmer should receive instruction relating to safe underwater practices at every stage in his training, to the end that he succeeds in developing an ability to dominate emergencies by habit.

At this point the trainee can be considered an underwater swimmer -- but what are the qualifications of an underwater swimmer? As yet there are no formal qualifications for underwater swimmers that are comparable to the deep sea diver ratings of second class, first class, and master diver. It is recommended that careful study be given the scale of abilities of underwater swimmers with aim in mind of drawing up qualifications for different levels of ability, and making suggestions for requalifications procedures. Once an underwater swimmer is qualified, he can then be trained in a number of other skills to perform many underwater missions. As a matter of present practice, these subjects are usually taught concurrently. It is emphasized here that underwater swimming composes a body of knowledge of itself and that performance criteria, curricula, training materials and the like are needed in order to formalize improved training procedures.

Present UDT training curricula vary among the teams and even between

successive classes. Instructor turnover and the absence of standards of performance contribute to the variations. There is as yet no established pattern for the training of UDT's in the additional skills of explosive ordnance disposal, guerrilla operations, etc. Training methods and organizations differ between the East and West Coast UD Teams. West Coast underwater demolition men receive their basic training in a school designed for the purpose and are then sent to the teams for advanced and on-the-job training. On the East Coast the entire training of the neophyte is accomplished by the teams themselves. Of course training should be continuous throughout the man's naval career, but the present underwater demolition man spends most of his tour of duty in training before he is considered thoroughly qualified for surface operational missions. This is even more serious in the case of submerged operations (SubOps) personnel, for they take longer to train. World War II experience indicates 3-4 months is required. Training facilities vary between the two coasts. West Coast teams have easy access to a swimming pool and the ocean is within walking distance of their headquarters, but they must put up with the relatively cool, not too clear waters of Southern California. The East Coast teams need auto transportation to reach sea water which is warm in summer, cold in winter, and always somewhat murky; they must travel to a nearby naval installation for scheduled use of a pool. During the winter season their advanced and submerged operations training is conducted in St. Thomas, Virgin Islands, where the warm, clear, calm waters provide ideal swimming conditions.

UDT's send men to Explosive Ordnance Disposal and Diving Schools for special training; conversely, other underwater units send their men to the UDT's for underwater swimming training.

Once the underwater swimmer is trained and in proper physical condition a new problem arises -- how to maintain him in good physical condition. At his home base, the problem is relatively simple compared to that existing during long periods of transport in submarines or surface craft. More information is needed concerning the best regime of exercises to maintain good swimming condition in a restricted and cramped environment.

04.03 Suggested Safety Precautions

Men, properly equipped and trained, can operate efficiently and safely in their foreign underwater environment to which they are not naturally adapted -- but in order to do so, they must be familiar with the rules imposed on them by this new medium and by their own physiological and psychological limitations. As with training curricula, there are no standardized safety precautions designed specifically for the guidance of SCUBA equipped underwater swimmers. An attempt to formulate such rules was made by the Panel's ad hoc Cooperative Underwater Swimmers Project in San Diego during the past summer. [2]

While not carrying the full endorsement of the Panel, these rules are presented here to give the reader a more complete understanding of some of the primary aspects of underwater swimming and of ways in which some of the dangers inherent in underwater swimming can be minimized. Perhaps these rules will seem restrictive when compared to the exploits of some of the experts in underwater swimming

but they are written for that mythical being, the average swimmer. For convenience they are divided into groups; those relating to the swimmer personally, his equipment, the art of swimming underwater, and the dive or operation.

SUGGESTED SAFETY PRECAUTIONS*

for use with
Self Contained Underwater Breathing Apparatus

I. The Swimmer

A. Must be psychologically and physically fit.

1. Must pass a complete physical examination which places special emphasis on the heart, lungs, ears, nose and throat. A history of sinus or respiratory ailments should almost always disqualify an underwater swimmer.

2. Must pass periodic (perhaps semi-annual) check ups, again with particular emphasis on the heart and respiratory systems.

3. Must "feel o.k." -- i.e., must not dive, nor be penalized for not diving when seriously desiring not to.

4. Must not dive after excessive drinking of alcohol until well rested and ill effects have passed.

5. Should be well rested (usually 8 hours sleep the night before dive) and when possible, should be permitted to rest after the dive.

6. It is highly desirable that the diver be "in shape". Regular exercises of running and skin diving have been found to be good conditioners for underwater swimmers.

7. Must like to dive. Underwater swimming should definitely be a volunteer activity. A reasonably reliable test of this is for the new swimmer to dive a few times with an experienced diver who can usually tell if the swimmer is enjoying himself underwater or whether he has some other motivation for diving.

B. Must be thoroughly qualified before being permitted to dive. Should be:

1. Trained in diving physiology, symptom's of diver's maladies and acquainted with the use of decompression tables.

* Unclassified with respect to security information.

2. Thoroughly trained in the use of his specific equipment. (Even the experienced diver needs to "check-out" on a new device before being permitted to dive with it.)

3. Trained in overcoming emergency situations e.g., running out of breathing gas, loss of buoyancy control, flooded equipment, loss of sense of direction, entanglement in marine growth or underwater objects, etc.

4. Familiar with diving signals.

   a. Hand signals

      (1) Visual

      (2) Rope pulls

   b. Sound signals

II. Swimmer's Personal Equipment

A. Must always be in first class operating condition.

1. Schedules should be set up for inspection of

   a. Regulators, valves, hoses, masks, etc.

   b. Cylinders, cannisters, gauges, etc.

   c. Harnesses, vests, belts, etc.

2. Swimmer must personally check operation and position of supply valves, reserve supply lines, and operating controls, immediately before entering water.

3. Prior to entering water, swimmer should check seal of mask, (by inhaling).

4. Swimmer should determine proper additional weight required for neutral buoyancy when wearing apparatus.

5. All equipment should be washed in fresh water and properly stored on the completion of the dive.

In addition to the SCUBA, it is highly desirable that the minimum personal equipment worn by the swimmer in [illegible]

1. Swim fins of correct size (1 pair for skin, 1 pair for suit)

2. Belt with knife. (Note: slip-hitches for all straps)

3. Belt and weights for buoyancy control.

4. Wrist watch

5. Depth gauge

6. Exposure suit in waters colder than 60° F.

7. Retrieving lanyard on face mask (if separate).

C. The swimmer may also desire to wear, or carry:

1. Compass

2. Plastic slate and pencil for recording instructions or observations.

3. Special equipment for the mission, such as fuse pullers, tools, etc.

4. Underwear in cool water, but where an exposure suit is not required.

5. Coral shoes and gloves when working on bottom or when emerging on shore.

6. Wear a nose clip but not recommended.

D. The swimmer should have available warm dry clothes to put on after dive.

E. The swimmer should never:

1. Wear ear plugs

2. Wear goggles

III. Care and Loading of Cylinders

A. Never fill cylinders beyond rated pressure.

1. Set up periodic inspection of cylinders for bulges, strains, etc

2. Never put O_2 in air SCUBA -- beware of oil coming in contact with O_2 under pressure.

3. Periodically inspect compressors and filters for contamination

of air supply.

4. Stow cylinders so as to avoid possibility of falling, or receiving shocks of any kind. Same for cylinders in transit or use.

B. Always use correct size wrenches on all fittings, and never force them.

C. Periodically calibrate gauges used for pressure measurements. Avoid oil in oxygen gauges.

IV. Underwater Swimming

A. An underwater swimmer should never swim alone, but always be accompanied by a "buddy". Buddies must have confidence in each other's ability.

1. Day -- visual range. (Note: in shallow clear water the buddy may be a surface swimmer, or a man in a boat.)

2. Night -- or reduced visibility -- use a buddy line (6' to 10' long).

B. The use of a floatation bag and line is highly desirable where it will not interfere with the operation. Dangerous operations may even require the use of a safety line.

C. Never ditch the SCUBA underwater unless all else fails. If it should fail, a free ascent may be made. If the SCUBA has positive buoyancy (as in breathing bag types) keep it on, use it for support on surface; if negative, ditch it.

D. Always keep breathing while underwater, particularly on ascent when the danger of air embolism exists. Excessive breath holding can also result in shortness of breath and eventually headache and nausea from CO_2 accumulation.

E. The swimmer should adjust buoyancy to slight positive when fully inhaled. Since gas is lost in open circuit apparatus positive buoyancy increases throughout the dive. It may be desirable to pick up a few rocks from the bottom to maintain optimum buoyancy.

F. Swimmer's rate of ascent should be leisurely and never forced. Thumb Rule: Never pass your small bubbles on ascent.

G. A diver must know how much breathing gas is in his SCUBA, and his own use-rate at the depth he is to operate. A margin of safety should be applied in calculating the limiting time for the dive.

H. During descent, if ears do not equalize during descent, ascend a few feet and attempt to clear eustachian tube blockage. If the ears cannot

be equalized, the diver should not continue to descend.

I. Underwater swimmers will meet unique situations which often cannot be anticipated. There is no cause for panic, when confronted with a new situation, or danger, the diver should stop and think his way out of it, for his instincts are not always reliable in the water environment.

J. When a swimmer loses visual contact with his swim buddy, listen first for his breathing noise, then signal by banging on bottles, or pieces of metal. If not located -- surface.

K. Before descending, the swimmer should check all his apparatus when immediately below the surface, signal his buddy, and if necessary -- wait for him then obtain permission of the surface man in charge of the dive to submerge.

V. Planning and Controlling the Underwater Swim

A. Gas supply, decompression time, temperature, and fatigue are the controlling factors in the dive, and not the amount of work to be done.

B. At all times it is highly desirable to have an extra "stand-by" SCUBA available on the surface. When the need for decompression is a possibility it is mandatory to have an extra unit along in the event the swimmers run out of air during decompression.

C. Swimmers must be familiar with the decompression tables, and be instructed on the limitations of each specific dive. Whenever possible, the dive should be limited so as to avoid the need for decompression. In deep dives in cold water instructions should be written on the swimmer's slate.

D. When decompression becomes necessary, and when other decompression equipment is not available, a weighted line should be lowered from the surface to the decompression depth for the swimmers. In the event a swimmer should run out of air while decompressing, another unit can be taken down to him, or, in emergencies the diver can surface, grab a SCUBA (do not take time to don it, or ditch the empty one) and immediately return to the proper decompression depth.

E. A qualified man should be in charge of the dive on the surface and responsible for the safety of swimmers. If he signals the swimmers to surface, they must do so immediately, but at a reasonable rate of ascent and within decompression restrictions if applicable. Regardless of rank or position, a submerged swimmer should not be in charge of the operation nor allowed to disobey the order of the one who is.

04.04 Conclusions and Recommendations

1. There exists no formal body of knowledge on the art of underwater swimming, and standards of performance for underwater swimmers are unknown. As a result, the training of swimmers varies from place to place and from time to time, and the principles of selection of men for swimming tasks have only an empirical basis.

2. Performance criteria for underwater swimming should be developed.

3. After these criteria are developed, a series of qualifications for different levels of underwater swimming ability should be established.

4. Only when it is clear what a swimmer can and should do, can standardized curricula be developed, instructors consistently indoctrinated, and adequate training material and facilities provided.

5. Training facilities, texts, and material aids are inadequate. Studies should be initiated toward designing and developing standardized training procedures tailored to the particular needs of underwater swimmers.

6. Further study should be given the questions of the best location for efficient and safe training of underwater swimmers, and whether swimming should be taught separately from the specific skills needed for reconnaissance, demolition, ordnance disposal, submerged attacks on shipping, and other missions.

05.00 EFFECTS OF UNDERWATER BLAST

Underwater blast constitutes an important problem to the swimmer because explosive energy is transmitted very efficiently by water. A man who would be unharmed by an air explosion of a hand grenade at 15 feet distance, providing he is out of direct line of the shrapnel, would undoubtedly be killed outright or die subsequently as a result of blast injury when a similar charge is exploded at the same distance underwater. Any swimmer may inadvertently be submerged when a charge is set off, and in warfare, military swimmers may be required to swim as close in toward a target as possible, even in the face of countermeasure explosions. Two practical questions thus present themselves: at what distance is a given size of charge likely to be dangerous and with what shockwave buffer mechanism may the swimmer be provided?

Even though the actual mechanism of damage to tissues is not clear, we can employ the well established theory of underwater explosions to obtain expressions for the distances at which different size charges will produce comparable effects in deep water. The following brief discussion draws freely on Cole's book, Underwater Explosion, [23] and on Hartman's report on this subject to the Panel on Underwater Swimmers [18]

When an explosive is detonated underwater the rapidly expanding gases generate a pressure disturbance which travels outward as a shock wave with a sharp

front. By the time this shock reaches the swimmer it is moving at a velocity about equal to the speed of sound in water, i.e., about 5000 ft. per second. Although the shock wave lasts for only a few thousandths of a second, the momentary pressure effects may be great enough to cause tissue damage. There are succeeding shocks resulting from oscillations of the gas bubble produced by the explosion, but their pressures are no more than one-fifth as large as the initial shock wave and hence are not important for our discussion.

A record of the pressure at any given distance from the explosion shows normal pressure just prior to the shock wave arrival; suddenly the pressure rises to a peak value, and then it dies away approximately exponentially. When the shock wave strikes a hard surface such as a smooth hard bottom, the wave is reflected, and only a small amount of the incident energy is lost. This reflected wave will at some points coincide in phase with the advancing direct wave, and in these regions of coincidence the pressure effects of the two waves will be additive. When the shock wave strikes a water-air surface, reflection also occurs but in this case the reflected wave changes from a pressure increase to a rarefaction. The rarefaction phase is transmitted from the point of reflection at about the same speed as the shock front. Recording a succession of pressures received just beneath the surface, one sees normal pressure succeeded by the shock wave, and then as the pressure begins to decrease exponentially, there is a sudden fall in pressure to considerably below the normal value. Near the explosion, this pressure reduction is sufficient to cause violent cavitation. The reduced pressure thereafter increases approximately exponentially toward normal.

The danger to an underwater swimmer lies in the fact that within his own body he has many water-air surfaces which are subject to these pressure-tension phenomena. The lungs, loops of bowel containing gas, the air passages in the throat and mouth, and the air sinuses in the head are the principal sites of injury due to underwater explosion. The parts of the body which do not contain air or gas transmit the shock wave practically without disruption, hence the muscles, bones, liver, heart, and brain are usually undamaged. In addition to the size and distance of the charge, many factors, including depth of explosion, depth of the swimmer, shape and character of the bottom, and refraction of the shock front because of temperature or salinity gradients in the water, all markedly effect the intensity and duration of the pressure disturbance reaching the swimmer, and therefore the degree of his hazard.

Although most experimenters consider that peak pressure is the determining factor in blast injury, careful and extensive work in the United Kingdom [5, 9, 13] indicates that the impulse and energy of the shock wave may be more important than the peak pressure. Blast impulse scales as $\frac{(W)^{2/3}}{d}$ (where w is charge weight and d is distance from the explosion), while peak pressure scales approximately as $\left(\frac{W}{d}\right)^{1/3}$, hence the safe distance from an explosion will increase approximately four times as rapidly with increasing charge weight if impulse is the principal factor determining injury rather than peak pressure.

Data on the subject are quite incomplete, but it is generally considered that even a determined man cannot continue to operate in an area in which peak

blast pressures of approximately 200 psi are encountered. A peak blast pressure of 300 - 400 psi will probably cause death within a few minutes. These numbers apply to a fully submerged, unprotected, swimmer. Assuming that peak pressure is the factor determining serious injury and deterrence, we can easily establish a relation which gives deterrent and lethal distances for a wide range of charges in deep water. The physical theory of explosions leads to an equation for the peak pressure in pounds per square inch from a charge of w pounds of TNT fired in deep water at a distance d in feet:

$$p = 2.16 \times 10^4 \left(\frac{\sqrt[3]{w}}{d}\right)^{1.13}$$

This equation is displayed in the form of a nomograph in Fig. 2. If we take 200 psi for deterrent, and 300 psi for lethal pressures, the equation gives us:

deterrent range in feet = 64 $w^{1/3}$ (lbs. of TNT)
lethal range in feet = 44 $w^{1/3}$ (lbs. of TNT)

These equations must be taken provisionally. At best, they hold for water which is at least [illegible] to [illegible] as deep as the distance from explosion to swimmer, so that surface and bottom reflections are relatively unimportant. In considering countermeasures, however, we may safely accept half the distance given by the equations as the range in which explosives will be quite effective against swimmers.

The information on deterrent and lethal underwater blast is fragmentary and inconsistent. Much of the work is invalidated because it was done in shallow water without pressure measurements. It is of utmost importance, both for development of countermeasures against swimmers and for our own swimmer doctrine, to obtain good experimental data in deep isothermal water on deterrent and lethal distances from different sized explosions. The lethal data should be gathered on large mammals, i.e., goats; much of the deterrent data can be obtained from humans.

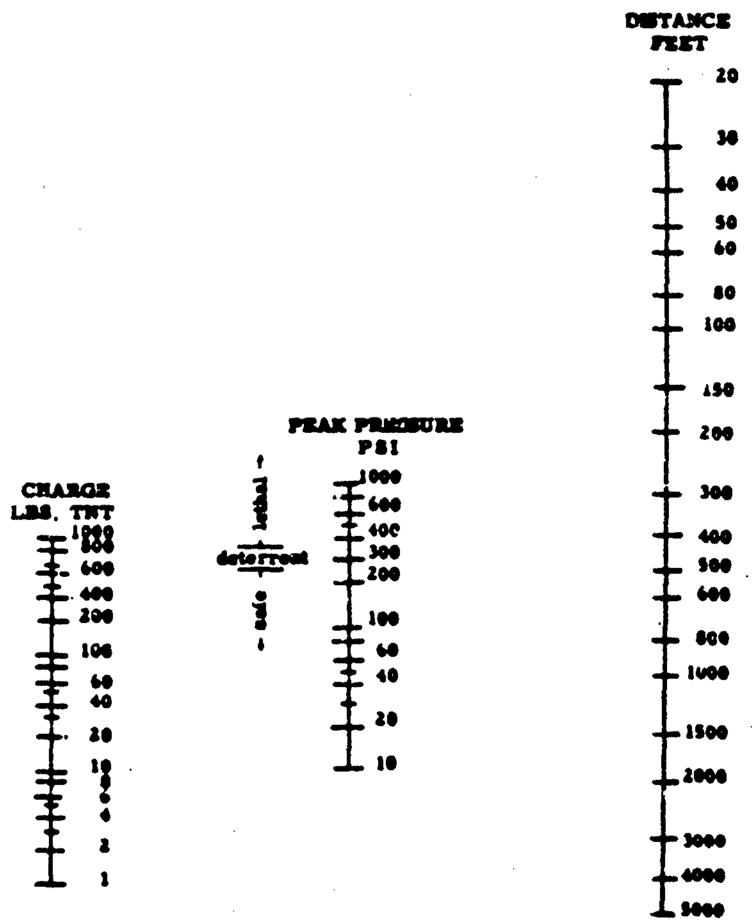
Experimental information is also needed on means of protecting swimmers against explosives. Much of this work can be done by enclosing blast gauges within test materials. Preliminary theoretical and experimental work indicates that a uni-cellular plastic suit would considerably reduce the peak pressure and impulse received by a swimmer. Injury to the unprotected underwater swimmer occurs because the blast wave passes nearly undiminished from the water into the flesh of the man. The pressure wave passes from water to flesh with little loss because the two materials have close to the same "acoustic impedance", i.e., the same product of density times sound velocity. The transmitted pressure wave can be made much smaller by interposing a layer of material with a widely different impedance. Approximate calculations can be made by well-known acoustical theory, and give the ratio of transmitted-to-incident pressure in terms of the impedance, Z_1, of water, and Z_2 of the protective layer.

Figure 2

Underwater Blast Nomograph

B

CHARGE WEIGHT, PEAK PRESSURE, and DISTANCE



$$\frac{\text{Transmitted pressure}}{\text{Incident pressure}} = \frac{4Z_2}{Z_1}$$

If the protective layer is foam plastic such as the neoprene used in the experimental "wet" suit, the approximate theory predicts a pressure attenuation by a factor between 80 and 200, depending on what value is chosen for velocity of sound in the neoprene. Unfortunately, there are no experimental data available yet to check the corrections of these predictions. The theory probably gives too optimistic a figure, and should not be trusted until experiments are made.

05.01 Conclusions and Recommendations

1. Underwater blast injury constitutes a serious potential hazard to underwater swimmers. In deep isothermal water there is danger of injury from a 1 pound charge at distances less than 65 feet, and at less than 300 feet from a 100 pound charge. Safe distances for large charges are uncertain, because it is not known whether peak blast pressure or total impulse from the explosion determines injury. Research should be continued on the basic mechanisms of underwater blast injury.

2. Explosions are likely to be included in enemy countermeasures and these may nullify or deter our underwater swimmer operations.

3. Protective clothing containing air or other sound-reflecting material might appreciably lessen the distance at which an explosive charge of given size is a serious hazard to a swimmer.

4. Research and development on methods for protection of swimmers against blast injury are urgently needed.

5. Reliable experimental data should be obtained on deterrent and lethal distances from explosive charges of different size. Until more such data are available, calculations for safe distances from known charges should be considered tentative.

06.00 SUITS

We begin this section with the assumption that underwater swimmers need suits primarily for protection against cold water. We will not consider other requirements such as protection against abrasion or toxins in the water because suits which gives p[illegible]tion against temperature can be designed to give some protection against these hazards. Protection against explosions is discussed briefly in the section on Underwater Blast.

06.01 Principles of Protection Against Temperature

The following paragraph is based on C. R. Spealman's report to the NRC Symposium on Underwater Swimmers, December 1[illegible] 7]

It is possible to calculate the approximate maximum and minimum water

temperature that a man can withstand for extended periods. Likewise one can calculate approximately the amount of insulation a man needs in water of various temperatures. For this purpose we may consider the human body as a heat-producing machine that does not operate very well unless its temperature is within certain limits. The body maintains its temperature by producing heat through the combustion of foodstuffs and it loses heat largely by conduction and radiation. As a heat-producing machine, the body can vary from a lower extreme of producing only about 40 kilogram calories per square meter of body surface per hour to an upper extreme, under great exertion, of producing about 2,000 kilogram calories per square meter per hour. This maximum amount of energy can be expended for only a period of about 20 seconds during a sprint. With reference to heat loss, a person at rest, cold though not shivering, loses heat through his body surface at a rate of about 9 kilogram calories per square meter per hour per degree centigrade. If he shivers, he loses heat at a greater rate, about 13 kilogram calories per square meter per hour per degree centigrade. This figure was obtained in water at 20 degrees centigrade; it is probable that in colder water, the heat losses increase. When the ambient temperature is high, warm skin loses about 50 kilogram calories per square meter per hour per degree centigrade. These figures neglect heat loss occurring by way of the lungs, but this loss is small. Man at rest in water above 96°F. overheats; if he is exercising, he will over-heat in water at 86°F.

There is great individual variability in the lower tolerable limit of water temperature and this immediately suggests a problem of selection. Most men will get along fairly well unprotected in water at 68°Fahrenheit. For the majority of men, sustained operations in water colder than 60°F. will require protective clothing.

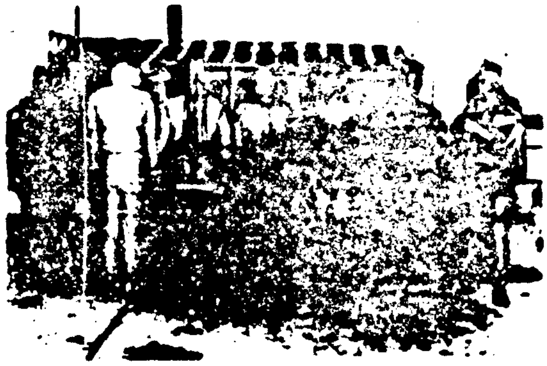
There are three principles in suits for protection against cold. One is to wear a water-tight garment over an insulating material such as wool underwear. Existing U. S. and the Italian Pirelli are examples of this kind. A second is to make the water-tight garment itself of an insulating material such as foam plastic. The French Dumas suit is of this kind. The third, exemplified by an experimental suit designed and built by Bradner [2] deliberately permits a small amount of leakage of water; warmth does not depend on air insulation next to the skin, but upon insulation incorporated in the foam plastic material of the suit itself. The amount of water permitted to flow through the suit without causing excessive heat loss can be computed roughly by assuming that the water warms up to skin temperature before escaping from the suit. It turns out that a total flow of 50 cubic centimeters per minute will [illegible] very small heat loss compared with the amount of heat generated by the body.

In the three types of garments, the swimmer is kept warm by air trapped between the cold water and the swimmer's body. Air, if it is prevented from moving freely between a warm and cold surface, is a very good heat insulator; the conductivity of a layer of "dead" air one centimeter thick being about 2.3 kilogram/calories/hr/m^2/deg. C.

With a dry suit over woolen underwear the spaces between the wool fibres

trap air, and thus provide good insulation as long as the underwear remains dry The wool itself has a conductivity of about 20, which is not far different from rubber(18). Water is only one-third as good an insulator as rubber (53). The conductivity of the underwear can be taken as the sum of the conductivities of wool and dead air, multiplied by the respective volumes they occupy in the underwear. If the wool becomes wet, its insulating ability falls to essentially the same insulation as still water. It is better than no protection at all, of course, since then there would be no dead water thickness and the skin would be continually in contact with the coldest water.

The other two suits (one wet -- one dry) are made of a material that holds the air entrapped, so that the insulation does not change even though the material is immersed in water. Foam plastic or a sponge, with all its holes blocked off, are such materials (unicellular expanded neoprene has been used for the test suits). The water trapped between the material and the swimmer is effectively warmed up to the temperature of the swimmer provided its volume flow rate is small. The water inside the suit serves no insulating function, of course, and a snug fitting suit is therefore desirable. This cotton underwear is recommended for use with the foam plastic dry suit for increased comfort and the absorption of sweat.



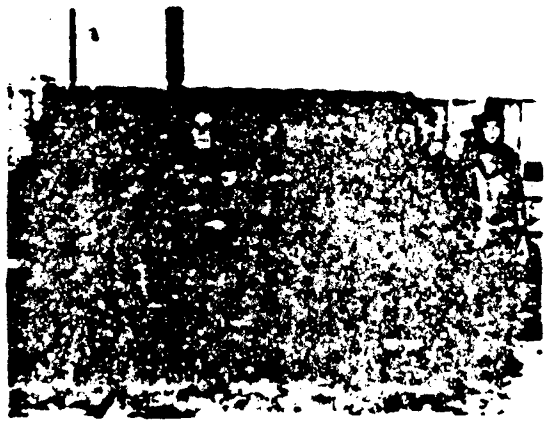


Fig 3(l to r) Clamp suit, two piece, double zipper, a "home made" suit, Pirelli, experimental gum rubber, U. S. Diver's ... rubber.

06.02 Status of Swimmer Suits

Table II, lists types of United States and Foreign Suits. All the standard U. S. Navy and sports diver suits depend on using woolen underwear for cold water operation, though very recently suits of unicellular plastic have been produced abroad and experimentally in the U. S. A.

06.03 Desirable Characteristics of Suits

Table I is a summary of the opinions of 39 experienced underwater swimmers concerning desirable characteristics of suits. From this it can be seen that the most important requirements are warmth, maneuverability, comfort (fit), and durability.

Table I

RATING TABLE FOR UNDERWATER SWIM SUITS

TOTAL NUMBER OF MEN INTERVIEWED: 39

Item	Extremely Important	Very Useful	Little value Compared w/others
Maneuverability	36	3	
Comfort at surface	36	3	
Durability	32	7	
Warmth	31	8	
No. of sizes needed	27	7	2
Danger from tears	25	13	1
Ease of entry and removal	22	16	1
Comfort at 60 ft.	16	14	9
Ease of field repairs	13	25	1
Adaptability to different temp.	9	23	7
Change in buoyancy with swimmer's orientation	8	12	19
Buoyancy at surface	4	15	20
Protection from blast	4	4	31
Fly opening	2	8	29
Change in buoyancy from surface to 60 ft.	1	19	19

06.04 Advantages of Foam Plastic Suits

Dry foam plastic suits:

1. Softness of material is such that movements are relatively free at all depths.

2. If the entrapped air in the suit is properly exhausted before submergence the small amount of air inside the suit and around the

Table II

STATUS OF SUITS

In Use

Designation	Type	Mfg.	Description	Remarks
clamp	dry	U.S. Rubber	World War II "Frog Man" - neoprene, canvass. Integral hood.	Production discont. Uncomfortable. Fairly dry.
1 zipper	dry	U.S. Rubber	" " "	" " " zipper leaks
2 zipper	dry	U.S. Rubber	" " "	Uncomfortable. Pinch on deep dives. Zippers leak.
Sport Diver	dry	U.S. Divers	Clamp type closure-Rubber full length, or torso only.	Cemented rubber, molded rubber both avail. for sport divers suits.

Under Development

waist closure	dry	---------	Similar to Italian "Pirelli"- Pure rubber	See Pirelli Suit.
Bradner	wet	---------	Non-watertight--snug fitting unicellular expanded neoprene or vinylchoride. Parka hood.	Comfortable at all depths.
waist closure	dry	DESCO	Lightweight waterproof nylon -waist closure-worn over polyvinyl chloride underwear.	

Foreign Suits*

Cousteau "Constant Volume"	dry	(Fr.)	Full suit with integral mask. Breathing air connects to suit.	Bulky, buoyant, and confining, but does not pinch on deep dives.
waist closure	dry	Pirelli (It.)	Natural Rubber, neat fitting-- waist closure; integral feet; neck and wrist cuff.	Very comfortable at sea level. Some pinching on dives of 30ft. Snags easily unless protected by coveralls. Waist closure often leaks.
Unicell-[illegible]	dry	Dumas (France)	3 types: short sleeves and legs bare; 3/4 sleeves, full legs; integral hood, arms, legs, optional gloves.	Comfortable at all depths; snags easily; nylon coverall, cotton underwear optional.
Dunlop	dry	Dunlop Aviat. Co. (British)	Full suit, with or without integral mask. Natural rubber, waist closure.	[illegible]tively desirable and comfort[illegible]. Usual squeeze on dives below [illegible]. Standard in Englan[illegible].

* Listing only suits which have valuable design features.

thin underwear, gives a relatively small change in buoyancy with depth.

3. The two piece suit with a roll type enclosure similar to the Dumas French suit is easy to don unaided.

4. Rips may change the character of the suit from dry to wet -- but the water entering the suit is trapped and can reach body temperature in a short while for the insulation has not been destroyed.

Wet foam plastic suit:

1. It does not need to be watertight. The problem of maintaining a watertight seal in any existing suit is extremely difficult. Furthermore, even if a suit it watertight, it may become wet from perspiration.

2. Rips in the suit material do not destroy its insulation. In "dry" suits a rip floods the suit. Replacing wool underwear by unicellular material would improve present suits.

3. Rips in the suit material do not affect the buoyancy or maneuverability of the suit. Present clamp type and zipper suits become less buoyant when flooded; and if the rips are large the suit has an effect like a sea anchor.

4. The suit can have openings for the elimination of excreta while the swimmer is in the water.

5. The suit will be equally comfortable at 100 foot depth or at the surface. Present UDT suits pinch and chafe as the air between swimmer and suit becomes compressed by outside water pressure on dives as shallow as 30 feet.

6. Preliminary experiments indicate that the buoyancy of the suit should not change as much with depth as does that of the present suits.

7. Air will not move back and forth inside the suit as the swimmer changes position. He will, therefore, not experience the awkward tendency to be upended when he lowers his head.

8. It is possible to make a "wet" suit which the swimmer can put on and take off himself, underwater if necessary.

9. It is possible to make a "wet" suit which can be left partly unfastened for coolness until just before, or even after, the swimmer enters the water.

10. Temporary or field repair is simplified since repair need not be leak-proof.

Fig. 4 An experimental model of a "wet" suit, with zippers open and hood down at right and at left zippers closed. Note mesh imbeded in foam surface to allow stretch but reduce excessive tearing.

06.05 Disadvantages

1. Wet suit requires more critical fit for maximum effectiveness.

06.06 Conclusions and Recommendations

1. None of the existing suits in use or in the process of development appears to be completely satisfactory for protection against cold water. The "wet" suit offers great promise for development into a satisfactory cold water suit

2. Study of optimum design and materials for "wet" suits should be undertaken. The only work done with "wet" suits under the cognizance of the Panel has been to confirm the principle of the suit. The problem of designing a "wet" suit must thus start approximately from scratch. Certain features of the experimental suits may be useful in designing an operational garment: 1) the extensive use of (non-watertight) zippers, laces, or snaps, to produce a snug fitting suit which can be donned by the individual swimmer; and 2) the use of a tough foamed neoprene, with a strong mesh which allows the suit to stretch in all directions and yet is rigid enough to prevent excessive buoyancy change.

3. Development of improved designs for dry suits should be continued: 1) the fit of current issue U. S. N. two-zipper suits needs to be revised with respect to such things as calf and thigh size, zipper length, fit around face, and number of suit sizes available; 2) efforts to improve the watertightness of zippers should be encouraged; 3) until watertight zippers can be guaranteed, a dry suit without zippers such as the Pirelli or Dumas should be used; 4) the possibility of avoiding suit squeeze in deep operations should be appraised. The Cousteau suit with automatic internal pressurization may have useful features in this regard; and 5) the Dumas French suits are recommended as a guide toward the development of an efficient dry suit.

4. Investigation should be continued on the physiological and human engineering aspects of protective clothing and related subjects.

07.00 SELF CONTAINED UNDERWATER BREATHING APPARATUS

Self contained underwater breathing apparatus (SCUBA) by name implies that the apparatus does not require the hose, line and other appendages which attach a conventional diver to his tending craft. Such equipment, therefore, frees the diver and enables him to undertake certain tasks which would be difficult or impossible to accomplish with a normal light-weight or heavy diving dress. However, it does not preclude the use of safety lines or added weights where diving operations indicate their need. This increased operational freedom imposes special training problems.

07.01 Operations with Present Equipment

Present equipment has extended the freedom of underwater man to perform many military operations completely underwater or partially underwater as the tactical situation dictates. Types of military operations now being undertaken include:

1. Reconnaissance

   a. For general intelligence

   b. For hydrographic intelligence

2. Demolition

   a. Beach obstacles

   b. Harbor installations

   c. Military bridges

   d. Moored shipping

3. Inspection (same as a-d in (2) above)

4. Underwater construction

5. Minor salvage tasks

6. Mine clearance

All of these operations can be conducted completely submerged by means of sortie and re-entry into a submerged submarine. However, many of them have reached only the experimental stage because of present equipment limitations. These vary with the type of apparatus and no single type of existing equipment satisfies all operational requirements.

The more important limitations are:

1. Small breathing gas capacity

2. Insufficient CO_2 absorption

3. Lack of streamlining

4. Poor durability

5. Poor reliability

6. Lack of comfort

7. Physiological limitations (Refer to 03.00)

8. Complexity

The compressed air open circuit equipment currently used in the U. S Navy was designed in France. Some of the parts were built in France and brought through Canada into the United States, other components were manufactured in the United States and complete units are now being built here. Although this equipment has been generally reliable, maintenance was complicated until recently by unavailability and non-interchangeability of spare parts. The current closed circuit oxygen equipment is of U. S. World War II [illegible] and is now at least nine years old

Recently, an order was placed for interim equipment designed and manufactured in Italy. This will provide for training until improved equipment can be designed and manufactured in the United States. Semi-closed circuit and mixed gas apparatus are only now being designed.

07.02 Training with Present Equipment

Training with the present types of SCUBA has been limited by lack of sufficient numbers of operable equipment and by the inefficiency of the equipment which is operable. Despite these difficulties training has proceeded to the point that each UD Team has a platoon in readiness for certain types of underwater operations. After a swimmer has been thoroughly indoctrinated in surface swimming techniques and surface missions, he may or may not be adaptable to further training for underwater work. The normal sequence of safety training in the diving tower, of day and night underwater swimming, and of submarine sortie and re-entry weeds out many. A few men qualify as operators of underwater craft and as members of the submerged operations platoon. (04 02)

07.03 Types of SCUBA

Self contained underwater breathing apparatus may be classified by the type of breathing gas circuit, that is, by the disposition of exhaled gas and of any excess gas supplied to the swimmer but not inhaled. On this basis we may divide these equipments into three types:

1. Open circuit -- each breath is withdrawn from the gas cylinder and exhaled into the water.

2. Semi-closed circuit -- exhaled gases are recirculated and part of the exhaled carbon dioxide is absorbed but there is a steady gas flow in excess of respiratory requirements into a rebreathing bag, and a discharge of excess gas into the water.

3. Closed circuit -- oxygen is supplied at a rate exactly equal to respiratory requirement, exhaled gases are recirculated and all carbon dioxide is absorbed. No gas is discharged into the water.

SCUBAS may also be classified on the basis of the breathing gas or breathing gas mixture supplied to the swimmer as follows:

1. Air

2. Oxygen

3. Nitrogen-oxygen mixture

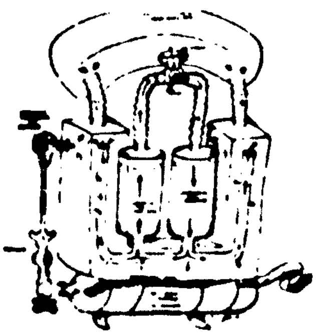
Helium oxygen mixtures, used in deep sea diving to minimize nitrogen narcosis and for shorter decompression of long deep dives, are not at present

used for self contained underwater breathing apparatus because of the danger of bends.

07.04 Description of Equipment

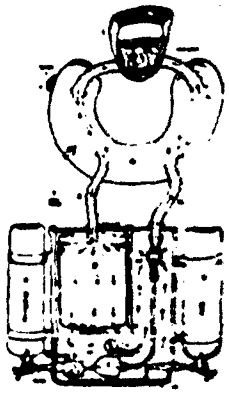
Open circuit. Open circuit equipment is in general the simplest type of SCUBA. Air or a pre-set mixture of oxygen and nitrogen is stored under high pressure (about 2000 psi) in cylinders. This high pressure gas is reduced to an intermediate pressure (about 55 to 85 psi) by a first stage reduction valve. The gas is obtained by the swimmer on inspiration through a second demand-type reduction valve which is actuated by respiratory action. The pressure of gas delivered to the swimmer is about equal to the ambient hydrostatic pressure. In some equipments (Aqualung and Northill) the two stages of pressure reduction are accomplished within the same valve casing. Other units (Scott, Emerson, Swedish) have the two valves in different locations. All exhaled gas is discharged as an intermittent stream of bubbles into the water and the utilization of gas is therefore equal to the mass exhaled.

Closed circuit. In the simplest type of of closed circuit equipment, oxygen is stored in cylinders under high pressure, and is admitted to a breathing bag either 1) through a manually operated valve, 2) by a slow steady flow through a pressure reducing valve, or 3) through a demand valve system similar in construction to that described for the open circuit equipment. When methods (2) or (3) (automatic oxygen supply) are used, a manually operated emergency valve is also fitted. Oxygen admitted into the breathing bag mixes with the reservoir of purified exhaled gas. The swimmer inhales from the breathing bag through a check valve. The slight pressure of exhalation closes the inhaling valve and opens an exhaling valve causing the exhaled gas to re-enter the breathing bag through a canister which contains carbon dioxide absorbent, normally soda-lime or baralyme. The rate of oxygen utilization from the cylinders is determined by the diver's



metabolic consumption of oxygen rather than by the larger volume of gas required for ventilation as in the open circuit type. Because of the danger of oxygen poisoning, present operating doctrine limits use of closed circuit oxygen apparatus to a depth of 30 feet for a period of 45 minutes.

Mixed gas equipment for closed circuit operations at depths greater than 30 feet is under long term study. Such equipment might employ a mixing valve which could be used to vary the rate of flow from two gas cylinders and an oxygen analyser to control the mixing valves. The use of a mixture of gas would reduce the physiological danger from oxygen poisoning, which is present when pure oxygen is used, but would introduce the new danger of anoxia. In addition is the problem of disposal of the excess inert gas on ascent.



Semi-closed circuit. Apparatus can be used for breathing either air, a mixture of nitrogen and oxygen, or oxygen alone. This type of apparatus consists of the same general components as closed circuit oxygen re-breathing apparatus and in addition employs a non-return exhaust valve to allow spill over of that portion of the gas flow which is not actually consumed by the swimmer. Near the surface the volume of excess gas released into the water is approximately one-fourth to one-tenth that of open circuit apparatus. A fraction of the exhaled carbon dioxide is also exhausted, resulting in a diminished load upon the absorption canister. In some types of semi-closed circuit equipment the breathing gas flows at a fixed rate directly into the re-breathing bag. In others, the flow is through a venturi orifice in order to facilitate recirculation of gas through the carbon dioxide absorption canister. Oxygen and nitrogen may be pre-mixed and carried in the same cylinder; alternatively, air or nitrogen, and oxygen may be carried in separate cylinders and mixed by a regulator. A type of SCUBA now under development (Emerson) is transitional between the open and semi-closed types. In this equipment a gas-saving mechanism is incorporated which stores the first part of each exhalation. Reinhalation of this gas containing minimal exhaled carbon dioxide should increase the diving time available with any given cylinder capacity. A present semi-closed type using nitrogen-oxygen mixtures (manufactured by the J. Blair Co.) is not safe for swimming at depths less than 30 feet because of the characteristics of the gas regulator system.

07.05 Relative Merits of the Three Types of SCUBA

Open circuit apparatus has two very great advantages; simplicity of design and operation, and absence of the hazard of oxygen toxicity. Its disadvantages are:

Table III

STATUS OF SELF CONTAINED UNDERWATER BREATHING APPARATUS

	IN USE	APPROVED, BUT NOT IN USE	UNDER DEVELOPMENT
OPEN CIR-CUIT	Aqualung (US Divers Co.) Air & Mixed N_2O_2		Scott Air Pack (Scott Aviation Corp.) Air & Mixed N_2O_2 [NAT EU evaluation]
			Airlung (Northill Co.Air Re'sch Co) Air Mixed N_2O_2 [development static]
SEMI-CLOSED CIRCUIT	British Universal (Dunlap Aviat. Co.) O_2 & N_2O_2 mixture [used in UK, demonstrated in U.S.]	N_2O_2 Outlet (J.P. Blain Co.) diving use only	Emerson (J.H. Emerson Co.) O_2 or N_2O_2 [to be submitted for tests]
CLOSED CIR-CUIT	LARU (WW II) (J.H Emerson Co.) O_2 [existing units - aged]	Pirelli (large LS901) (Pirelli Co.) O_2 [under procurement for interim use]	LARU (New) (J.H. Emerson Co.) O_2 [under development contract]
		Pirelli (small S701) (Pirelli Co.) C_2 [under procurement for interim use]	LINDA (or "WHITE BEETLE") (Old Dominion Res'ch Co) O_2 to 30', mixed gas deeper [under long term development]

93 to 98 percent of the gas carried in the cylinder is lost without being used for metabolism; the presence of nitrogen involves danger from bends and nitrogen narcosis; the stream of bubbles rising to the surface greatly increases the risk of detection; with present equipment, the intermittent, high-frequency noise of the gas flow gives some risk of detection by sonar.

In closed circuit oxygen equipment all the gas carried is used for metabolism and the rate of oxygen utilization from the cylinder is determined by the diver's metabolic consumption of oxygen rather than by the larger volume of gas required for ventilation. Hence, for a given duration of submerged operation only about 1/15 to 1/30 the gas volume used in the open circuit apparatus is required. Further economy is gained because the rate of oxygen utilization does not increase with increased depth, whereas the mass of gas withdrawn per unit time from open circuit equipment is approximately doubled at 33 feet, tripled at 66 feet, and quadrupled at 99 feet. With closed circuit equipment a trained operator can move under water without any trail of escaping bubbles except during rapid ascent when expansion of gas in the bag and lungs causes some spill-over. The small rate of withdrawal of gas from the pressure cylinder results in a very low noise level, thus further minimizing the risk of detection. There is no danger from bends because there is no nitrogen absorbed in the tissues.

On the other hand, closed circuit oxygen equipment is somewhat more complex in design and operation than open circuit equipment because of the added components of the carbon dioxide absorption system and a re-breathing bag. A definite disadvantage is the limitation of depth of operation because of the danger of oxygen toxicity. The length of safe diving time with oxygen decreases sharply below 33 feet.

When used with oxygen, semi-closed circuit apparatus has essentially the same limitations and advantages as closed circuit apparatus except for somewhat diminished duration of operations (because some oxygen is exhausted and not consumed) and probably higher risk of visual and sonar detection.

When used with nitrogen-oxygen mixtures, semi-closed circuit apparatus enables work to be accomplished at depths equivalent to those permissible with mixed gases used in open circuit apparatus. Deeper diving is possible than with oxygen alone because of the reduced hazard from oxygen toxicity. If the percentage of nitrogen is less than in air, the danger of bends is reduced and the maximum time of operation is increased. By varying the nitrogen-oxygen mixture the most advantageous gas ratio for maximum diving duration with minimum danger of oxygen toxicity or bends can be achieved. Diving duration is also increased for a given time of operation since semi-closed apparatus requires only a fraction of the gas needed for open circuit equipment (at 100 feet approximately 1/20). Unlike the open circuit equipment, the rate of gas flow need not increase as work or depth increases.

The principle disadvantage of semi-closed circuit mixed gas equipment is that failure or maladjustment of the gas regulator can, without the swimmer's knowledge, expose him to excessive concentrations of nitrogen or oxygen and

SELF CONTAINED UNDERWATER BREATHING APPARATUS
RELATIONSHIPS OF DIVING TECHNIQUE TO MAJOR FACTORS
LIMITING DIVING DEPTH AND DURATION

		SKIN DIVING	CLOSED CIRCUIT		SEMI-CLOSED CIRCUIT		OPEN CIRCUIT			HOSE SUPPLIED DIVING	
		AIR	O_2	N_2-O_2	O_2	N_2-O_2	O_2	AIR	N_2-O_2	AIR	He-O_2
Related to Depth and Time	Bends			x		x		x	x	x	x
	Narcosis			x		x		x	x	x	
	O_2 Toxicity		x	x	x	x	x		x		x
Related to Ascent	Bends			x		x		x	x	x	x
	Aero-embolism		x	x	x	x	x	x	x	x	x
Related to Equipment Design	Breath. Resist.		x	x	x	x	x	x	x		
	Anoxia	x		x		x					
	CO_2 Excess	x	x	x	x	x	x	x	x	x	x
	Dead space		x	x	x	x	x	x	x	x	x
	Absorption efficiency		x	x	x	x					x
Related to Equipment Failure	Anoxia		x	x	x	x	x	x	x	x	x
	O_2 Toxicity			x		x					
	Bends			x		x					
	Narcosis			x		x					
Minimized by Training and Regulations	Bends			x		x		x	x	x	x
	O_2 Toxicity		x	x	x	x	x		x	x	x
	Aero-embolism		x	x	x	x	x	x	x	x	x

hence to the hazards of bends or oxygen toxicity. The danger of anoxia also exists if the flow of the oxygen component of the gas mixture becomes inadequate for metabolic needs, either because of failure of the gas supply malfunctioning of the pressure regulator or because of work-rates in excess of those for which the equipment was designed. The inability of man to recognize the onset of anoxia makes safety in semi-closed circuit apparatus, using mixtures of nitrogen and oxygen, dependent upon maintenance, design and mechanical perfection of the gas flow regulator rather than upon the skill and training of the swimmer himself.

07.06 Present Operational Requirements for Self Contained Underwater Breathing Apparatus

Present operational requirements for self contained underwater breathing apparatus, as determined cooperatively by Fleet activities and the Bureau of Ships are generally as follows:

1. Open circuit equipment. Normal depth of operation 0 to 150 feet with sufficient breathing gas volume to permit 60 minutes of operation at 50 feet and a maximum depth of operation of 200 feet for about 1 minute (for safety purposes such as submarine escape, etc.)

2. Closed or semi-closed circuit equipment. Normal operating depths 0 to 60 feet, with a maximum depth of 100 feet for use in submarine sortie and re-entry; sufficient breathing gas volume to permit two to four hours of continuous underwater operations including swimming 2.5 miles at 0.75 knots.

Provisions are needed for both open and closed circuit apparatus which would permit attachment to additional gas supply units built into an open cockpit underwater vehicle. [1]

07.07 Desirable Performance Characteristics of Self Contained Underwater Breathing Apparatus

Any self contained underwater breathing apparatus should have as many of the following characteristics as possible:

1. It should be fairly light in air.

2. It should remain near neutral buoyancy in water, both when the gas bottles are full and when they are discharged.

3. It should be small, and streamlined in relation to the swimmer's body.

4. It should possess maximum simplicity and reliability of operation.

5. All controls should be readily operable by a swimmer wearing

gloves.

6. Such physiological hazards as oxygen toxicity CO_2 poisoning and bends should be minimal.

7. Rate of deterioration and requirements for maintenance should be small.

8. Magnetic signature, noise output, sonar target strength, and visible bubble trail should be low.

9. It should be comfortable for the swimmer and should interfere as little as possible with his freedom of movement and operating effectiveness.

10. There should be a minimum of components in front of the swimmer.

11. Removal under water should be easy, with minimum self-flooding.

12. The face mask should fit comfortably, with a wide field of vision, and be capable of use with or without a mouth piece.

13. The mouth piece should be soft and tasteless, and capable of being spit out and retrieved without removing the mask.

14. There should be provision to warn the swimmer when the breathing gas supply is approaching exhaustion.

15. The equipment should be operable in water temperatures from 27° F. to 90° F.

16. The mask design should provide for voice communication.

17. Closed circuit apparatus should be usable under conditions of hard work, that is rapid rate of production of CO_2.

18. An attachable snorkel for surface breathing is desirable in order to economize on stored breathing gas.

At present it is not possible to combine all these desirable characteristics in a single "universal equipment". Therefore different types of apparatus have been designed and are being tested or procured for different operational needs.

07.08 Conclusions and Recommendations

1. No present type of SCUBA is adequate fo[r all t]ypes of underwater operation. Fundamental research in the physiology of breathing under pressure, and development of improved equipment with wider flexibility and greater endurance

is needed.

2. Open circuit, closed circuit and semi-closed circuit types of SCUBA each have distinct advantages and disadvantages. Each type is best adapted to aid in accomplishing certain underwater swimmer's missions, and the decision as to which should be employed must usually rest on the Field Commander, based on actual operational possibilities.

3. Maximum security and/or the need for continuous underwater operation over a relatively long period will in many cases require that a closed or semi-closed circuit type SCUBA be employed. But for many operations requiring use of SCUBA, the simpler open circuit equipment can be employed.

4. Efforts should be directed toward intensified study and development of carbon dioxide absorbent materials, and of substances which both absorb carbon dioxide and release oxygen (e.g., high oxides of potassium and the chelates) for use in closed circuit oxygen and mixed gas SCUBA. Correlation of research now in progress by government and civilian agencies to determine applicability to SCUBA should be continued.

5. There should be continuance of development of SCUBA from operational, safety and physiological viewpoints, aiming at increased security, work capacity and submerged operating time of the equipment commensurate with man's bodily endurance and ability to do useful work. Improvement of open circuit, closed circuit and semi-closed circuit apparatus to achieve: 1) lower breathing resistance; 2) increased gas economy (in open and semi-closed circuit types); 3) more effective carbon dioxide absorption (in closed and semi-closed types); 4) streamline form; 5) simplicity and reliability of operation; 6) simplicity of maintenance; 7) maximum field of vision; 8) minimum magnetic signature; and 9) minimum sound output and echo target strength.

6. Competition in SCUBA development and production is constantly growing, stimulated by increasing military requirements and public interest. This healthy commercial situation should bring more and better models into existence, provide new principles of operation and insure safer and easier operation.

7. Investigation of the feasibility of a safe closed circuit mixed gas SCUBA should be continued.

8. Continued study is required of quantitative laboratory and field methods of testing breathing apparatus with the purpose of improving validity of tests and obtaining basic information of value in improving design.

9. Factors responsible for resistance to respiration in SCUBA and means of minimizing them should continue to be studied.

08.00 COMMUNICATIONS

Among the many new sensations experienced by the neophyte underwater

swimmer is a sense of great quiet. The multitude of sounds he continually hears in his natural environment all but disappear as he dives into the sea. In its place are a few waterborne sounds from nearby motor boats, swimmers breaking the surface, and a consciousness of the swimmer's own "noisy" breathing. The underwater man is now in a medium into which communications originating in the air hardly penetrate. Airborne sound is reflected from the sea surface, while infrared, radar, and radio are strongly absorbed. Without special equipment underwater swimmers are cut off from each other and from their parent craft.

In any type of combat or reconnaissance team in the armed services, whether it be an entire naval task force or a 12 man army squad, communication in one form or another is the nerve center of the operation. Without a versatile and adequate means of communication to the various elements, valuable time is consumed and only limited and inadequate information can be transmitted. Regardless of the extent to which other underwater swimmer equipment is perfected, if a poor method of transferring intelligence exists, or if only one means is available, the missions will undoubtedly be extremely difficult and may even, on occasion, be unproductive of results. Because of the present lack of an adequate means of communication with the parent craft, current doctrine for Underwater Demolition Teams states that once a team is committed to the water, the action cannot be recalled and is inflexible for all practical purposes. The Explosive Ordnance Disposal man cannot use a wire-connected telephone for fear of actuating a magnetic mine. The oceanographic research swimmer cannot relay his observations to the surface without the limiting wire -- and none of these have at present any means of communicating with each other except for crude measures such as tapping two iron bars together.

Means of communication are needed between individual underwater swimmers between the swimmers and their parent craft, and occasionally between the swimmer and the beach or aircraft. For convenience, the communication requirements can be divided into several categories:

1. Swimmer to submerged swimmer or submarine.

2. Swimmer to surfaced swimmer or surface craft.

3. Swimmer to aircraft.

4. Swimmer to dockside or other shore station.

The swimmer should be able to transmit and receive while he is completely submerged, operating on SCUBA, or with his head out of the water breathing air. In all cases (except aircraft) the medium common to all of the communicants is the water, which suggests its use also for communication by underwater sound, underwater electric potential (UEP), or other means of energy propagation.

With the exception of the special non-magnetic requirements of EOD personnel, an analysis of UDT communication requirements will apply to practically all other underwater swimmer communication needs. The known UDT missions

cover tactical situations varying from operations in which secrecy is of no importance, to tactics which require the utmost in stealth. Obviously, the choice of the communication method to be used will be greatly influenced by the tactics to be employed. Available communication media which might have application singly, or in systems combination, are:

1. Radio
2. Infrared
3. Underwater electric potential
4. Direct wire
5. Underwater sound

All of these methods of transmission and reception have advantages and disadvantages and their employment or rejection depends greatly, but not wholly, upon the tactical situation. A review of the characteristics of each may be enlightening.

First, let us consider radio. Radio can furnish satisfactory range; it can furnish adequate bandwidth; it can be acceptably packaged for all known assignments; it can supply two-way intelligence, a necessary factor for most situations. It has two disadvantages. First, means of interception and countermeasures are well known and their use can be expected. Second, and probably more serious, once the user goes underwater, communication and guidance are lost unless a trailing surface antenna is used.

Let us look next at infrared. Again, its ranges appear adequate and its packaging can be acceptable. It can be intercepted by an alert and properly equipped enemy, but it probably has better security than radio. It is severely affected by atmospheric conditions and also requires an unobstructed path. It will be difficult to equip a swimmer with satisfactory transmitting equipment but receiving equipment is possible, as exemplified in the so-called "Beanie". Once the swimmer goes underwater, the link is broken. (Refer to paragraph 09.00 for more on infrared.)

How about Underwater Electric Potential? UEP, having been a rather neglected means of communication might initially offer a considerable degree of security because the enemy might not be expecting it. Its range is probably short, although this may be a disputable point. It no doubt could be packaged acceptably and it has the advantage of being usable by either surface or submerged elements. It seems fair to state that UEP cannot yet be dismissed and serious studies of its behavior should be continued.

What is the case for direct wire? Under certain tactical situations direct wire -- submarine to harbor or beach -- offers unquestionable advantages. It is the only means that offers absolute message security, it can easily be packaged

and the equipment can be very simple. It may very well fit in nicel with other means of communication. For instance, as one component of a communication link between a submarine and a harbor, or beach, the wire could terminate in a remote underwater sound transducer thus concealing the true location of the submarine and effectively increasing the sonar range and security. As far as is known, direct wire has never been used in UDT work but study of its employment for UDT purposes seems justified in view of its relative simplicity and high security.

What are the advantages and disadvantages of communication by means of underwater sound? The ranges seem to be adequate. Packaging, for swimmers use, although at first glance apparently quite difficult, is now known to be possible. Security, while obviously far from absolute, is probably adequate under most conditions. The established acceptance of sonar -- and the existance of suitable equipment on submarines and surface ships lends encouragement for its adoption. Sonar can be used by all the UDT elements; submarines, boats, surfaced and submerged craft, and surfaced and submerged swimmers at all times and under all weather conditions. If used discreetly, and any system of radiation has no real security and must be used discreetly, sonar appears to offer more and to be restricted less than any other communication means except the direct wire.

Some trial models of an underwater telephone (UWT) were made by OSRD during World War II for possible use by the Maritime Unit of the OSS. [24] The specifications were never clear and work was discontinued in June 1945 after only a few experimental models of UWT were built. These utilized audio frequency electric currents in water, now commonly referred to as underwater electric potential (UEP). Ranges of approximately 160 yards were obtained between swimmers and 600 yards between boats. The experiments were hurried and development was stopped before an operationally satisfactory unit was produced.

Another wartime development (October 1944 to March 1946) was an acoustic underwater telephone system known as "the Gumps", consisting of three units, Andy, Min, and Chester. Andy was a transmitter, that could emit an 800 cycle cw homing signal or be used for voice communication. It was designed for small boat use, weighed 10.6 lbs. in air, 5 lbs. in water and was about 14 inches in length. Min was a smaller unit used as a receiver by a swimmer. Chester, the third unit, was a small transmitter for swimmer use. The mean frequency of operation of this set of telephones was 53 kc. Ranges up to 2500 yards on voice and 4000 yards on the homing tone were obtainable. The bearing accuracy of the homing signal was about 8°. The devices were never used in combat and work was discontinued at the end of the war.

The U. S. Navy Underwater Sound Laboratory, at New London, has been designated as the responsible agency for the development of electronics pertinent to swimmers and amphibious problems. It has developed a new underwater swimmer's telephone. The swimmer's two-way telephone uses a single side band suppressed carrier type of modulation. Using a carrier frequency of 8.0875 kc it works with either the AN/UQC-1, or the AN/BQC-1 underwater telephones. It transmits and receives the speech band of 250-3000 cycles per second. It also

transmits but does not receive, an 8.0875 kc tone on which the parent submarine can obtain, via JT sonar, a bearing accuracy of 1° on the swimmer for navigational purposes. The swimmer's telephone develops about 0.8 electrical watts output to a transducer which has about 43% efficiency. It has an operating life of 6 hours from its self contained battery pack.

Fig. 5 Underwater Telephone (early model)

The swimmer's telephone is comprised of four units; the telephone proper, the transducer, the headphones, and a microphone. The telephone proper including a six hour battery pack is a rectangular belt mounted rubber box 7" long by 2 3/4" wide by 5" deep, pressure proofed to 100 pounds per square inch. It weighs about 7 pounds in air and 1.5 pounds in water (neutral buoyancy will be achieved in new models). It has two controls, a selector switch, and an off-on switch. The bone conducting headphones are miniature units and are also pressure proofed for watertight integrity. These headphones are held in place by means of a specially designed adjustable band. The microphone, although waterproof, is arranged for mounting inside a face mask; if used with an Aqualung, the swimmer must surface. The transducer is a barium titanate unit roughly the size and weight of a two cell flashlight. When held horizontally, it has a 105° beam, but when suspended vertically, as from the swimmer's belt, it is omnidirectional. All the electronic components, including tubes, are cast in resin in plug-in assemblies for ruggedness and ease of maintenance. Remarkable reliability has been achieved; in over 1 years rough and varied use, no tube or component failure has occurred in any of six telephones. Figure 5 shows an early model of the telephone with an unmounted microphone.

The performance as achieved in Navy evaluation of these swimmer telephones has been approximately as follows: a) swimmer-to-swimmer range -- 2,000 yds., b) swimmer to parent submarine range -- 10,000 yds.

The 10,000 yard swimmer-to-submarine range has been realized through the development of an adaptor which enables the submarine to utilize its highly efficient JT transducer as a directional receiver of the swimmers transmissions. The Underwater Sound Laboratory has been recently devoting its efforts to developing similar telephone units for the surface craft. These in general are similar to the swimmer's telephones, but of higher power (15 watts), with many attachments, such as towed transducers peculiar to boat needs. With these equipments it is expected that surface boats will be able to communicate with all elements of the UDT operations, and, if required, to direct their operations. This gear is scheduled for Navy evaluation in November 1952, February and March 1953.

08.01 Conclusions and Recommendations

1. A satisfactory means of underwater sound communications among swimmers, submarines and large surface craft utilizing underwater sound has been developed and is believed ready for naval procurement. Underwater sound communications equipment for use between swimmers and small surface craft is about to be evaluated and should be ready for procurement shortly. While this is a big advance, underwater sound is not necessarily secure, so efforts must continue toward developing a secure underwater communication (and navigation) system.

2. Underwater Electric Potential (UEP) and direct wire methods should be further investigated as alternate means of underwater communications because of their greater security as compared to sonar.

09.00 ELECTRONIC AIDS TO NAVIGATION

The difficulties of underwater navigation, resulting from the absence of land marks, the short range of visibility, and the marked effect of currents on the position of a slow moving object, may well prove to be the limiting factor in underwater swimmer operations. Present means of navigation with a compass and flutter board (essentially similar to the taut wire system used by Marine surveyors) do not overcome these difficulties but they have the advantage that they do not disclose the presence or the position of the swimmers. Any aid to navigation, such as a guiding beam, that involves energy propagation through air or water greatly increases the risk of detection and at least partially nullifies the ability to operate secretly, and thus to achieve surprise, which is the most important characteristic of offensive underwater swimmer operations.

For certain missions, such as mine hunting and underwater inspection in friendly waters, secrecy is not paramount; for others, a calculated risk of detection may have to be taken in order to reach the objective. Under these conditions aids to accurate navigation might be most useful

Two types of electronic navigational aids for use underwater are conceivable.

1. The swimmer may follow a directional beam emitted by an underwater beacon or cable, or by a parent craft.

2. He may himself emit or relay a signal which gives his position to the parent craft; the latter, in turn, may record this information for later use or transmit guidance instructions back to the swimmer.

The advantage of the second type is that it can give range from a fixed reference point, as well as direction. The disadvantage is the decrease of security which inevitably results from use of a non-directional transmitter. But this may be minimized by sending only short, irregularly intermittent signals. In either type, the thinking and computation necessary to solve the navigational problem should be done by the parent craft or beacon, rather than by the swimmer.

UNDERWATER SWIMMERS

Use of a guidance beam to direct underwater swimmers towards bottom mines was attempted by the Navy Electronics Laboratory -- National Research Council Cooperative Research Group on Mine Hunting, in the summer of 1951. Using a modified and waterproofed standard Zenith hearing aid, the swimmers were able to follow a 90 kc 60° fan shaped sonar beam down toward a bottom mine. Ranges of only 20 to 30 feet were obtained with the breadboard model, probably because of the very low power output of the transducer (less than 1 watt). But the test demonstrated the feasibility of using a narrow acoustic beam to guide the swimmer he could hear easily within the beam and experienced a sharp cutoff as he left it.

A second type of electronic aid to navigation has been investigated by workers at the Underwater Sound Laboratory, New London, as part of that Laboratory's program of electronic development for underwater swimmers. Using JT Sonar to listen to signals emitted by the swimmer telephone described in paragraph 08.00, a parent submarine has been able to determine the bearing of a swimmer within 1°. By sending a range interrogation pulse which is relayed back from the swimmer's telephone, the submarine can measure the swimmer's range as well as his bearing. Range resolution down to about 10 feet has been obtained in preliminary experiments, and it is expected that the equipment will operate out to about 4,000 yards. It appears feasible to enclose the ranging equipment within the existing swimmer telephones without increasing their size; it is expected that the equipment will be ready for demonstration during the spring of 1953.

In cooperation with the University of Michigan, workers at the Underwater Sound Laboratory have developed and tested a series of infrared equipments for swimmer and boat navigation above water. The swimmer unit is called the "Beanie" and is a small metal box (5" x 1½" x 3", 2½ lbs.) worn on top of the swimmer's head and held on by a helmet which also contains earphones. The box contains a photoconductive cell that can receive voice, code, or a steady tone from the ship or submarine. An on-off switch is the only control. Other units of this infrared family are: the type "W", a 20-pound portable voice communication unit; type "S", a 30-pound voice communicator unit designed primarily for submarine use; type "E", a large 500-pound receiver for 60, 90, and 120 cps signals; type "K" transmitter unit for a 12" searchlight; the X-29B IR Beacon used as a beach marker; the C-3 IR Receiver (8 pounds) which converts infrared images into visual images electronically; and the AM IR Receiver which uses a phosphor-button to convert the infrared image into a visual one. In addition there is under development a Periscope IR Communication system. These units showed promise during tests. (Refer to paragraph 08.00 for more on infrared.)

09.01 Conclusions and Recommendations

1. Electronic aids to navigation may prove useful in types of swimmer operations where secrecy is not paramount, or where a calculated risk of detection can be taken.

2. Promising results have been obtained in preliminary trials of both

guidance beams and two-way communication systems for underwater navigation as well as with infrared equipment for use above water.

3. Because use of electronic aids to navigation will inevitably diminish the secrecy with which underwater operations can be conducted, further development should be guided by an operational analysis of the navigational and other requirements of the several applications of swimmers.

4. The difficulties of underwater navigation resulting from the absence of land marks, the short range of visibility and the marked effect of currents on the position of a slow moving object may well prove to be the limiting factor in underwater swimmer operations. Unique and ingenious methods of what might be called "passive" navigation are therefore required.

10.00 UNDERWATER PHOTOGRAPHY AND TELEVISION

10.01 Introduction

The principal military use of underwater photography and television is to relay visual intelligence to commanders and others who need it. The underwater swimmer can rarely describe what he has seen with sufficient accuracy and completeness. This difficulty increases with depth because the well-known narcotic effects of breathing air or mixed gases under pressure interfere with lucid thinking.

By rising for an instant above the water surface, the underwater reconnaissance swimmer, equipped with a suitable camera, (for example with infrared film) can also obtain close-in photographs of beach and shore installations which not only supplement his verbal description but can be used to determine where he has been. Where maintenance of complete submergence on the part of the swimmer is required, it might prove feasible to equip the underwater camera with a small periscope for use in this "pop-out" photography. Conceivable use of a camera such as the Land, which provides an instantaneously developed picture, could aid a surfaced swimmer to locate himself by comparing the infrared photograph he has taken with a series of reference photographs.

Until recently, the necessity for using bulky diving gear to operate underwater and the fact that cameras and television equipment were clumsy and hard to handle, have limited military and public interest in the arts of underwater photography and television. The development of self contained underwater breathing apparatus, recent advances in small compact photographic and television cameras and the increasing popularity of underwater swimming have all served as stimuli to this field.

The increasing public interest in underwater swimming has brought new people, bringing with them new ideas, to solve the problems of underwater photography. Underwater demolition men, botanists, biologists, geologists, archaeologists, amateur and professional photographers and Navy research workers have all attempted to take better underwater pictures. As a result of this new interest many

underwater cameras have been developed and a great many pictures taken. As yet, the United States can claim no results equivalent to those produced by the Undersea Research Group of the French Navy, headed by J. Y. Cousteau, which has done more to advance the field of underwater photography than any other agency or person. Under French leadership, underwater photographs have graduated from the fuzzy, indistinct pictures of the past to realistic true color pictures of the world underwater.

10.02 Problems Associated with Underwater Photography and Television

Light. Under normal conditions photographs can be taken with natural sunlight, with good results to depths of 20 feet. Below this depth, photographs taken with natural light lose contrast because of the scattering of the light and the absorption of the red and yellow portions of the spectrum by the sea water. The narrowing of the spectral band width causes the loss of shadows and results in flat and uninteresting pictures. As the light becomes weaker with increasing depth, the iris of the camera must be opened. This in turn, reduces the depth of focus. Despite these difficulties color pictures of good quality can be taken in clear water and bright sunlight at depths of more than 50 feet, while black and white film can be used with natural light at depths greater than 100 feet. The French have achieved good success in water as deep as 200 feet in the exceptionally clear waters of the Mediterranean Sea.

Color pictures taken below 20-30 feet with natural light have a predominant blue color. For example air tanks of divers, which are a bright yellow at the surface, photograph as blue green at these depths. The use of a magenta filter helps somewhat to restore the color balance of deep water pictures, but the reduction of light by the filter is usually too great for good results. If color corrections are desired, they can best be made during development. For still color pictures at depths, good results have been obtained by Cousteau [7] with ordinary flash bulbs as a light source. No single self contained artificial light source is yet available for underwater moving pictures.

Turbidity. The turbidity of the sea depends both on the particulate matter in suspension and the pigments dissolved in the water. Pure water is relatively transparent, and in it photographs could be taken at great distances if the light source were sufficiently powerful. In the sea, however, light is scattered as it passes through the water and objects at a distance disappear as if in a fog. Because of the higher organic productivity and the presence of particulate matter brought by rivers, coastal water are more turbid than water far from shore.

Various methods have been attempted to reduce the effects due to scattering, which shows up on a photographic plate as "stars" or "fog". Because infrared red light is not scattered as easily as the blue and green wave lengths, its use has been suggested to overcome the effects of scattering. The high absorption of the longer wave lengths in water counteracts this advantage however and makes the use of infrared impractical. Polarization of the light has also been attempted to reduce scattering effects but has not proven satisfactory because of the loss of light intensity during polarization.

In extremely turbid water, pictures may be taken through a clear plastic box filled with filtered water. This method allows the photographer to increase the field of view without increasing the amount of turbid water between the camera and the object being photographed. The bulky equipment required limits the method to special situations. Scattering effects from artificial light sources in areas of turbid water may be partially eliminated by placing the lights as far to one side of the camera as practical or as close to the object as possible but shielded from the camera lens.

10.03 Underwater Photographic Equipment

Present status. The greatest weakness in the field of underwater photography today is unavailability of reasonably priced equipment. Cameras commercially available at the present time are expensive and in most cases are imports from France, Britain, or Italy. Although they are in general excellent equipment many are not designed specifically for use by military underwater swimmers. Presently available commercial American cameras are of excellent quality but are quite expensive and rather heavy in air. Present Navy underwater cameras are too bulky for use by underwater swimmers.

Many underwater cameras have been developed by American skin divers and other amateur underwater swimmers. Developments by and for these groups are potentially a rich source of ideas and equipment for military swimmers.

Still cameras. A still camera for use underwater should be inexpensive (cost less than $100) because of the danger of loss and flooding with sea water. Underwater cameras can be made from several existing commercial air cameras by simply enclosing them in water-tight casings. This method is desirable as it allows the underwater swimmer to use the camera in air to take pictures of the beach, and to replace with little effort cameras which have become damaged or inoperative. The quality of "O"-ring seals has improved to the extent that they can be used on all outside controls without danger of leakage within the depth limits of the underwater swimmer. The case should be made of a strong light material such as aluminum or lucite.

Lucite has been used with good success to encase cameras at the U. S. Navy Electronics Laboratory, and by Dr. Hugh Bradner. It has the advantage of being transparent, thus allowing the operator to see what is happening when he is taking pictures. Cameras having a reflex action are desirable for accurate focusing underwater. A light meter should be placed in the camera case for accurate determination of exposure time and aperture setting. The camera case should have the following external controls: 1) film advance, either automatic or manual; 2) iris control; 3) focus control; and 4) shutter speed control. In addition the case should be designed so that it can be opened and closed rapidly.

The choice of a camera to be used in the underwater camera case depends on the type of work to be done.

Motion picture cameras. Most of the desirable characteristics of still

cameras apply to motion picture equipment. Cases should be designed around commercial 16 mm or 35 mm press cameras equipped with wide angle lenses. External controls should include mechanical wind, on-off trigger, iris and focus control. Windows on both ends of the case are desirable to give vision through the case and thus better determination of the field being photographed as well as a view of the working parts of the camera. A slight positive buoyancy is useful because it keeps the head of the diver in an upright position and permits recovery of the camera if it is dropped. A light meter should be placed in the camera in such a way that the light sensitive element is affected by the same area as the lens of the camera. A view of the footage counter is also essential.

10.04 Underwater Television Equipment

In 1946, in connection with the resurvey of Bikini Atoll, television was adapted to a housing for use underwater for the first time. This initial use of TV was made possible by the development of the image orthicon tube which is sensitive to extremely low light intensities. Although few useful scientific results resulted from this test, it demonstrated the feasibility of underwater television. Recently, attention has again been focused on underwater TV because of the successful identification of the sunken British submarine AFFRAY at a depth of 280 feet in the English Channel after the wreck was located by sonar.

The above equipments required a housing about the size of a 50-gallon drum, a tripod, and several cables. Although underwater swimmers or divers can assist somewhat in the maneuvering of such ponderous gear, their size is such that these equipments tend to supplant rather than supplement the underwater swimmer. However, with recently developed photo-conductive tubes such as the Vidicon, it has proved possible to build a light and compact television camera. One such camera (the RCA ITV series) weighs about 10 pounds and is about the size of a 16 mm cine camera so that it can be readily housed in a case which an underwater swimmer can handle. This equipment requires a monitor on shipboard but a cable as long as 500 feet can be used between the camera and the monitor. Although the length of cable is sufficient for vertical descents below a ship it does not allow much horizontal maneuvering. The equipment should prove useful for mine identification, salvage operations, and inspection of underwater structures; for example, an underwater swimmer might locate a mine but not know how to disarm it. The TV camera then would be useful in relaying a picture of the mine to an ordnance expert at the surface who could give detailed instruction on the method of disarming.

The main advantage of television over the cine camera is the instantaneous relay of visual intelligence to an expert observer at the surface. However, the picture quality of television is still much poorer than photography. This is especially true of the thermo sensitive tubes which display considerable "memory effect".

Present TV cameras are about as sensitive to light intensity as the human eye. However, it is difficult to obtain sufficiently wide angle vision. Like the unaided eye and the photographers camera, underwater television is limited by the

turbidity of the water. By electronically enhancing contrast, and by increasing the sensitivity of television tubes to long wave lengths (thus reducing effects of scattering) it may be possible to develop TV cameras which are considerably more effective than the eye.

10.05 Conclusions and Recommendations

1. Underwater cameras and accessory equipment are not readily available in this country for scientific or military use by underwater swimmers and those units that are available are very expensive.

2. Equipment which is available in most cases has been designed for other types of diving and is not, in general, applicable for operational use by underwater swimmers.

3. Exchange of information with French and other foreign underwater swimmers and photographers should greatly aid development of adequate United States photographic equipment for military and scientific uses.

4. Underwater television equipment manipulated by swimmers should prove useful for identification of mines and other submerged objects, for salvage operations and for inspection of underwater structure. The possibilities of electronically enhancing contrast suggest that underwater television may be made more effective than the human eye as a means of seeing underwater.

11.00 SHIPS, BOATS AND CRAFT

11.01 Introduction

The limited range of unassisted swimmers (particularly if they must carry equipment or explosives) makes it necessary to transport them as near to the objective as possible. At present, reconnaissance swimmers are carried almost to the objective in large ships (APD or submarine), which approach to a safe distance and put the swimmers off in small craft (LCPR's or rubber boats). These also approach to a safe distance, which may be all the way to shore or several hundred yards off the beach, before the swimmers and their gear are finally released.

The desirable characteristics of small craft for underwater swimmers depend on the kind of work the men are expected to do and the nature of the mother ship. When operations must be conducted with stealth, the boats should be quiet, have low sonar target strength, and be difficult to see, either visually or with radar. If search and survey equipment, cameras, explosives, buoys, or other bulky gear are to be used stowage space must provided in the boats. For landings on ocean beaches, the craft must have good surf characteristics. It must be designed for easy handling and stowage on the mother ship (particularly if the latter is a submarine). If it is necessary to hide [illegible] it ashore it must be light and easy to handle out of water. For nearly all tasks the boat should be sturdy and capable of high speed operation.

For extended underwater search, penetration of enemy harbors, or optimum effectiveness in secret reconnaissance of enemy shores, a mechanical means of propulsion under water is needed to increase the swimmer's range and speed. This may be either an equipment to aid the individual swimmer or a submersible which will carry two or more men and their equipment.

11.02 Parent Ships

The APD. The surface vessel most commonly used as a parent ship for the UDT's is the destroyer transport (APD), about 306 feet long, displacing approximately 1800 tons in fully loaded condition, and varying in maximum speed from 22 to 25 knots. In addition to space for crew and ship's officers, these ships have quarters for 12 officers and 150 men, but they sometimes carry two underwater demolition teams (26 officers and 200 men). Messing facilities are inadequate even when only one team is embarked and the supply of fresh water is often severely restricted. There is no shop space for the UDT's to use in maintaining their equipment and in repairing their boats and suits. The boat davits are unsatisfactory for boat handling in rough weather, and the positions of the boats in the davits while the ship is underway make it quite inconvenient to work on them.

Submarines. There are no submarines specifically designed as parent vessels for Underwater Demolition Teams. UDT's in Korea have at times worked from one of the two submarine transports (ASSP) now in operational use. Although the deck hangar on the ASSP is large enough to house a boat the size of an LCPR the problem of carrying the swimmer's craft on a submarine should be further studied. Should they be towed or carried in cradles or tubes on the deck? How then should they be protected against pressure? Should they be carried inside the submarine? The transport of any surface craft aboard a submarine and the inherent requirement that it be launched on the surface fail to capitalize on the most important feature of the mother submarine -- its relative invisibility when submerged.

A means for more rapid egress and re-entry through the escape chamber of the submarine is needed. At present the men wait to go out 2 to 5 at a time. Coming back, they are taken in board in groups of three. Serious difficulties arise if the swimmers have nearly used up their gas supply. These might be alleviated by fitting breathing tubes outside the submarine hull, which the men could use on their return from a mission. Such tubes carrying air or a gas mixture would also be most helpful if the men have been breathing oxygen in operations at shallow depth and then must descend to 100 feet or more in order to re-enter the submarine. Using a tank designed by Belloni [10] the Italians have been able to lock and unlock 12 men per minute into or out of a submarine. (Refer to paragraph 03.m in Submarine section.)

11.03 Small Surface Craft

The LCPR. The LCPR is the standard UDT reconnaissance craft. The LCPL (similar to LCPR but without a ramp) is also used. Both are employed to transport swimmers and their gear from the parent craft to the launching positions,

to move the explosives and equipment of the team ashore after "D" day, and for many miscellaneous purposes. These boats are 36 feet long, 11 foot beam, weigh 18,000 pounds in hoisting condition, and are capable of 12-14 knots if they are "souped up" and the armor is removed. They carry a portable radio to contact the mother ship, but usually do not have echo sounders or other standard navigational gear. They get their approximate location off the beach by dead reckoning from the release point, by radio guidance from the mother ship, and whenever possible by visual comparison of the shore with aerial photographs. Because of their high silhouettes these boats can be seen in clear weather for about 5 miles. Swimmers are launched overside from a 7-man rubber boat (towed on the port side aft) and picked up underway in a similar manner. The large bow wave produced by the LCPR seriously interferes with this operation.

The following requirements for a small surface craft have been suggested:

1. The boat should fit standard davits on APD's (or better davits should be designed).
2. The silhouette should be as low as possible.
3. The gunwale should be sufficiently low to permit easy handling of a rubber boat so that swimmers may board or go overboard easily.
4. Good visibility is needed for the coxswain, to facilitate swimmer pick up.
5. The boat should be able to beach and operate in the surf.
6. 15-20 knot speed is desirable -- with lowest possible bow wave to keep from swamping swimmers and to reduce visibility.
7. A screen should be fitted on one side so that swimmers going over the other side cannot be seen.
8. 50-caliber or 30-caliber machine gun mounts which do not obstruct the coxswain's view are desirable.
9. The boat should be lightly armored on the sides.
10. Silent operation at three-quarters speed is desirable.
11. A waterproof stowage compartment should be provided for the radio and there should be a permanently installed antenna base.

The Bureau of Ships has prepared preliminary designs for a boat to succeed the present LCPR. A portion of this craft will be completely covered and heated. The boat will have a self-bailing cockpit where the swimmers get in and out of

the water. On the center line, aft of the coxswain, is to be a 50-caliber twin machine gun mount. The coxswain will be able to sit or stand if he likes in such a position that he can see his line of swimmers for pickup operations. The boat-officer's location is an open cockpit on the port side. A 300 horsepower diesel engine will be installed. But it is believed the 20-knot requirement cannot be fulfilled unless a gasoline engine is used. The boat has a low gunwhale on the port side for discharging swimmers. Perhaps the low gunwhale and screen features should be interchangeable so as to increase flexibility in surface UDT tactics. A difficult design problem has also arisen because of the attempt to provide stowage space for 2,000 pounds of explosives. This may be an excessive requirement.

<u>Rubber boats.</u> The 7-man rubber boat (formerly the LCR, now IBS) is currently a most important piece of UDT equipment and is used on almost every surface operation; for launching and picking up swimmers from the LCPR, for transporting swimmers when a moderate degree of stealth is required, for reconnaissance in cold water, for sounding and profiling when conditions allow, and for moving explosives to the beach.

Presently used boats are heavy (325 pounds) awkward to handle, difficult to hide on the beach and to lift aboard the LCPR. They are quite durable and rugged, however, and capable of quiet, foolproof operation. Some boats are inflated by CO_2 bottles, others by manually operated pumps (which takes about six minutes). Recent information from Korea indicates that they can be tracked by radar at distances up to 6,000 yards.

An improved rubber boat should be lighter, at least as stiff, and tear-resistant as present craft. In the present boat, stiffening is provided in part by a removable corrugated mat which is inflated to make a rigid deck aided by a 2" sponson, and in part by the heavy material of the boat itself. A statistical study of puncture hole locations in the present rafts might allow the use of materials of varying thickness to save weight in the less exposed areas. The mere reduction of weight would make the boats easier to handle and would doubtless reduce the puncturing somewhat even though a lighter weight material were used. A specially reinforced section is required to hold anchors and heavy sharp objects.

A new 7-man rubber boat has been built by the International Latex Company. Although it weighs only about 85 pounds it is said to be as rigid as the present model. Its durability remains to be proven. Flotation is given by 18 separate bladders, all inflatable at one time from a common air supply in the splash rail that encircles the boat. The bladders are made of polyvinyl chloride (each can be replaced separately when necessary) but the rather fragile plastic material is protected by a very heavy nylon. The bladders can easily be repaired in the field with a special tape.

<u>Paddleboards.</u> Paddleboards have proved valuable to the UDT's and should be re-evaluated. Two types have been used: one, the stock board, is of sturdy construction and capable of carrying a load of 2?0 pounds plus the operator. It can travel one mile in approximately 15 minutes. The other type, the racing

board, is of fragile construction, carries only a minimum of weight, and must be handled by an expert. It can travel one mile in approximately 12 minutes.

This difference in speed, balanced against the consummate skill required for the racing board, does not seem to justify use of the latter for military purposes.

Other surface craft. Recently the Bureau of Ships investigated a small "skim boat". It is essentially a surf board with an outboard motor fitted on the bow, with an underwater exhaust to reduce noise, capable of 25 knots with a 10 horsepower engine, and carrying two men. A boat of this type would be valuable for high-speed reconnaissance, for use on a night operation, or for an emergency pick up.

Another craft, the British commando Kayak, has been tested in Korea and found useful as a replacement of the rubber boat on reconnaissance missions.

An item of equipment which could well be improved is the presently used two-man "flying mat" -- a small rubber raft equipped with a small portable electric motor and batteries. Extreme difficulty in securing the electric motor with clip-on devices seems the main objection to the flying mat. The flying mat is ideal for night surface stealth work, and it is useful equipment for UDT's. Its drawbacks might be rectified in a minimum of time.

11.04 **Small Submersibles**

Uses. Whenever it is necessary to operate near an enemy held shore in as complete secrecy as possible, the approach to the objective must be made under water. The first part of the approach can be made in a fleet type submarine, but these 1500 ton vessels cannot operate submerged in water shallower than 60 feet and depths less than 150 feet are considered hazardous. The final submerged approach must be made by swimming, or in a small submersible. On many coasts throughout the world, depths less than 60 feet extend out several miles from shore. In these areas, even men equipped with SCUBA would not have enough breathing gas to swim the distance and return. Moreover, they would be seriously fatigued when they reached their objective after their swim of several hours. To supplement their swimming, they must have a small, powered submersible, or a mechanical means of individual underwater propulsion.

In World War II, the Italians and the British pioneered in the use of small submersibles for stealthy attacks on shipping. These craft can also be used to carry demolition and other gear for swimmers, to conduct rapid and accurate reconnaissance of enemy held near-shore areas, for harbor defense, and possibly for terminal guidance to long range missiles.

It should be emphasized that because of the small number of men who can be transported in a midget submersible, the general use of these craft might markedly alter the doctrine and tactics of such groups as UDT's.

Types. Small submersibles can be divided into two classes:

1. Open-cockpit craft, in which the compartment occupied by the crew is flooded when submerged. The British Sleeping Beauty (SB) and the Italian SSB, are examples of this class.

2. Closed-cockpit craft in which the crew compartment is filled with air. The British one-man Wellman boat, and their X Craft (5-man midget submarine) are of this type.

Present status. there are at present no U. S. made small submersibles. Several small foreign models have been tested including the British Wellman, Sleeping Beauty (SB), X Craft, and the Italian SSB.

The Sleeping Beauty is a one-man open-cockpit craft, self propelled by a small electric motor. On the surface it can be towed, sailed, paddled or driven by its own propulsion system. Its designed underwater speed is 2.5 knots, but UDT's have never been able to achieve more than two knots with it; its operating range is 10 to 20 miles.

The closed-cockpit Wellman boat carries one man, weighs about 2½ tons and is 20 feet long. Its maximum speed is about 4 knots and its range at this speed is about 30 miles It carries a 560 pound warhead which is manually detachable from the craft by the operator.

Fig. 6 The Sleeping Beauty. Note also the nylon collapsible boat in foreground and rubber rafts in background.

The X Craft is a midget submarine 50 feet long, displacing 28-30 tons and carrying up to five men.

The Italian SSB is a 2-man open-cockpit craft powered with a 7½ horsepower motor and capable of submerged speeds up to five knots. It carries water ballast in internal tanks.

The Bureau of Ships has drawn up a pre... ry design of an open-cockpit craft similar to the Sleeping Beauty and of a closed-cockpit 25- to 40-ton midget submarine. A contract has been let to the Fairchild Aircraft Corp. (Engine Division) for this latter craft.

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UNDERWATER SWIMMERS

Desirable characteristics:

1. The craft should have a submerged cruising speed of at least 4 knots. This minimum submerged speed is necessary to facilitate the launching and retrieving of the boat from moving submarine, to enable it to proceed at will in areas of strong currents, to reduce the time required to carry out a mission, and to facilitate evasive maneuver under attack. The highest possible maximum speed consistent with other requirements is desirable for the latter two purposes, because the risk of detection will increase with the time that the craft is in enemy-held waters, and its chances for evasion depend almost entirely on submerged speed.

2. The required submerged endurance time is dependent on the type of mission, varying from 2 hours to 8 hours.

3. The craft should be capable of carrying at least two men. The "buddy" system of two men working together has been found to be essential for safe underwater operation, (04.03) and in nearly all types of underwater missions, two men working together as a team can be much more productive than two men working individually.

4. The operators must be protected from cold water. When sitting quietly in water, men soon become very cold even at water temperatures of 80°. (04.01) In an open cockpit boat, protection from cold could be obtained by an insulated or heated suit. The contained air in a closed cockpit boat usually furnishes sufficient insulation.

5. The air pressure inside the boat should remain equal to the outside water pressure, or the rate of change of pressure should be small enough to prevent aeroembolism.

6. Men should be able to enter and leave the boat easily when it is submerged.

7. It should be possible to moor the boat easily while it is submerged, so that the occupants can leave it in order to accomplish a mission, and find it on their return.

8. There should be a built-in breathing gas supply and if necessary a carbon dioxide absorption system.

9. It should be possible for a small team of underwater men to stow, launch, and retrieve the boat from the deck of a submerged, moving submarine

1. Open-cockpit craft, in which the compartment occupied by the crew is flooded when submerged. The British Sleeping Beauty (SB) and the Italian SSB, are examples of this class.

2. Closed-cockpit craft in which the crew compartment is filled with air. The British one-man Wellman boat, and their X Craft (5-man midget submarine) are of this type.

Present status. there are at present no U. S. made small submersibles. Several small foreign models have been tested including the British Wellman, Sleeping Beauty (SB), X Craft, and the Italian SSB.

The Sleeping Beauty is a one-man open-cockpit craft, self propelled by a small electric motor. On the surface it can be towed, sailed, paddled or driven by its own propulsion system. Its designed underwater speed is 2.5 knots, but UDT's have never been able to achieve more than two knots with it, its operating range is 10 to 20 miles.

Fig. 6 The Sleeping Beauty. Note also the nylon collapsible boat in foreground and rubber rafts in background.

The closed-cockpit Wellman boat carries one man, weighs about 2½ tons and is 20 feet long. Its maximum speed is about 4 knots and its range at this speed is about 30 miles. It carries a 560 pound warhead which is manually detachable from the craft by the operator.

The X Craft is a midget submarine 50 feet long, displacing 28-30 tons and carrying up to five men.

The Italian SSB is a 2-man open-cockpit craft powered with a ½ horsepower motor and capable of submerged speeds up to five knots. It carries water ballast in internal tanks.

The Bureau of Ships has drawn up a preliminary design of an open-cockpit craft similar to the Sleeping Beauty and of a closed cockpit 25- to 40 ton midget submarine. A contract has been let to the Fairchild Aircraft Corp. Engine [illegible]

10. The boat should be small enough so that several can be carried by a submarine, preferably inside the pressure hull to protect the boats from high hydrostatic pressure. If the craft are carried inside the hull of existing submarines their dimensions and shape must be such that they can be launched through the torpedo tubes.

11. The boat should be capable of surfaced operation and of submerged operation down to 100-150 feet.

12. In order to avoid detection, the boat should be quiet even at cruising speed, have a low sonar echo target strength, and a low magnetic signature.

13. To facilitate handling, both above and below water, the boat should be light in weight.

Relative merits of open-cockpit and closed cockpit craft. Closed-cockpit craft have the advantages that the crew and their equipment can remain dry and warm, and the power plant does not have to be waterproof. This is almost essential for the larger sized boats such as the X craft. No complex, built-in breathing equipment is necessary, though carbon dioxide absorption and breathing gas stored under pressure are required for extended submerged operations. They have the disadvantages that they must be heavy to enable buoyancy compensation; and cannot be easily entered or left, so that the operators are virtually cut off from direct contact with their environment. They also are better sonar and magnetic targets.

Open-cockpit craft have the advantages that they can be light in weight with low inertia under water; that the crew can enter and leave easily, without necessity of going through an air lock, to perform missions which require direct manual contact with submerged objects, and that the hull does not have to be pressure-proof and therefore can contain transparent windows. Also their echo target strength and magnetic signature are lower. They have the disadvantage that the crew will become chilled, unless protected by insulated or heated suits, that a more complex breathing system is necessary, and that equipment and machinery must be waterproofed.

11.05 Individual Underwater Propulsion

For many purposes, a means of underwater propulsion for individuals is needed in which the swimmer remains in the water and rides or hangs onto the vehicle. Such an "underwater motorcycle" would be powered, or driven by the swimmer's own efforts, have neutral buoyancy, and be steerable. It does not need speed higher than necessary to overcome the speed of underwater currents, but should be capable of operating for several hours and have a cruising range of at least several miles. The swimmer should be able to anchor or moor it outside the surf zone and to recover it after leaving the beach. Dimensions should be sufficiently small so that half a dozen or more could be launched from small

landing craft or submarines.

Several efforts to design an underwater motorcycle are already underway. USNUSL has made sketches and models of hand-held collapsible torpedo-shaped craft, the prototype of which is said to be under construction. Aerojet of Pasadena has made a preliminary model using a pedal drive from the swimmer's legs to a propeller. Gray and Halegard of Los Angeles, and Davis developments have submitted sketches of a number of varying shaped craft which might be suitable, and offered to conduct a development program. Keogh-Dwyer has designed and built an underwater propulsion unit weighing about 43 pounds and powered by silver batteries, which was satisfactorily tested in a swimming pool in Norfolk. Fuller development is continuing.

11 06 Conclusions and Recommendations

1. The limited range of unassisted swimmers, particularly if they must carry equipment or explosives, makes it necessary to transport them as near to the objective as possible.

2. For present surface UDT operations where one or two teams of 113 officers and men each are employed, a somewhat larger and better fitted surface ship than the APD would be desirable.

3. A better small surface craft than the LCP(R) is also required. It should have 15--20 knot speed, low silhouette, minimum bow wave and other features designed to meet the specific needs of Underwater Demolition Team swimmers. Development of lighter and more easily handled rubber rafts should also be continued.

4. Whenever it is necessary to operate near an enemy held shore in as complete secrecy as possible, the approach to the objective must be made under water. The first part of the approach can be made in a fleet type submarine, but for the final approach, a small submersible to be carried and launched by the submarine is needed. For these submerged operations certain modifications of fleet type submarines are desirable to facilitate egress and re-entry of swimmers and for stowage and launching of small submersibles.

5. The desirable characteristics of small underwater craft for underwater swimmers depend on the kinds of work the men are expected to do and the nature of the mother ship. In general, the boats should be quiet, have low sonar target strength and magnetic signature, be as nearly invisible as possible, and have adequate storage space, speed, endurance, and seaworthiness.

6. Open and closed cockpit, small submersibles each have advantages and [illegible] which [illegible] them for [illegible] types of underwater missions. Models of both open and closed cockpit small submersibles should be designed and built for experimental use by United States underwater swimmers, in order to fully develop the operational possibilities and requirements of these craft. Because of the small number of men who can be transported in a small submersible, the

general use of these craft may markedly alter the doctrine and tactics of UDT's.

7 In the design of small submersibles, problems of stowage and launching from a moving submarine must be taken into account as well as the need for adequate speed to overcome currents and to allow evasive tactics, endurance, ease of egress and re-entry, safety and comfort of the crew, and minimum detectability.

8 Man's efficiency as a swimmer is very low: that is, only a small part of the energy he expends in swimming is effective for propulsion. An "underwater bicycle" is needed which would either be mechanically powered or would link the swimmer's muscles to the water in a more efficient manner. Development of means of propulsion for individual underwater swimmers should be vigorously pursued.

12.00 UNDERWATER OBJECT LOCATION

Detection of mines and man-made obstructions is a necessary part of many military operations in in-shore waters. Most of the obstacles and some of the mines will be found proud of the bottom, but many mines will be partially or fully buried in the shifting sands and soft muds so frequently found in shallow waters. Under some circumstances underwater object locators operated from surface craft or submarines will be effective for mine and obstacle detection. But under other conditions it will be desirable, and in some cases necessary, to employ underwater swimmers for mine and obstacle detection, and particularly for identification and disposal of the threat. If the swimmer emerges from the water to operate on the beach he may be faced with additional problems of buried ground mines. Disposal of underwater obstacles off a beach in advance of an amphibious landing is one of the primary missions of Underwater Demolition Teams.

Mines and other obstacles vary considerably in size, shape and character of material. Some contain a considerable mass of iron or steel; others may be non-ferrous and non-magnetic. To complicate the problem further, the mines may be actuated by one or a combination of sensing mechanisms; the most common being magnetic, acoustic, pressure, and contact.

At present the swimmer is, for all practical purposes, limited in object detection to his own senses of sight and touch. In harbors visual ranges frequently approach zero and tactile methods can only achieve a maximum search width of about 6 feet -- the length of the swimmer's arms. In order to extend the range of detection and to assist the swimmer in identifying the objects detected, an underwater "flashlight" is needed to supplement his senses. The following are among the desirable performance characteristics of such a device:

1. The maximum possible detection range is of course needed, but any range in excess of visual or tactile is acceptable if not too expensive in terms of cost or operational inconvenience.

2. The device should be small enough to be carried or towed by an unaided swimmer or should be operable from a small underwater vehicle.

3. It should be operable when the swimmer is completely submerged, when he is swimming on the surface, and if possible when he is above water on the beach.

4. It should operate under conditions of very low visibility.

5. It should function over the range of water temperature conditions tolerable to a swimmer (generally 29° to 96°F).

6. It should be able to detect ferrous and non-ferrous objects that vary in size from a few inches (e.g., a fused hand grenade) to many feet (e.g., a tetrahedron) and that may be floating in the water (e.g., a moored mine), resting on the bottom, or buried several feet deep in mud or sand.

7. Its presence should not actuate a mine or booby trap.

8. The usual requirements of ease of maintenance and operation, long shelf life, construction from non-critical materials, and capability of mass production should be met, if possible.

There is no device at present that even approaches the above requirements. A Sonar flashlight, the QAA (USDAR) was developed during World War II, but it had many limitations which rendered it unacceptable. [24] Of the other developments of World War II and the post-war period, the magnetic detection device designated as AN/PSS-5, is perhaps the best, even though it was not designed as a swimmer's underwater object locator, but rather as a land mine locator, and was simply waterproofed for underwater use. But its range on a 15" metal sphere is less than 1 yard and it is quite bulky to use.

The inability of swimmers to locate and identify underwater objects is not unique and much effort is now being directed throughout the Navy towards development of equipment for this purpose, particularly for mine hunting systems. Possible utilization of a wide range of physical properties in which mines differ from the natural environment is being studied. The unique characteristic of the swimmer in this field is his ability to carry the detection gear closer to the object than is possible by other means and rationally to direct its operation.

12.91 Conclusions and Recommendations

1. In the development of mine hunting equipment, advantage should be taken of the ability of underwater swimmers to carry and direct detecting and identifying devices close to mines and other obstacles.

13.00 BUOYS

Underwater swimmers are an important sensing mechanism of the surface fleet, because they see and feel the bottom in more detail than is possible to achieve with any other method. It is, of course, essential that they be able to

mark their underwater finds suitably -- with buoys. Reefs and obstacles, mines and traps, channels, boat lanes, wrecks and areas all need to be buoyed for warning or guidance to surface craft. Although the basic requirement for a floating marker seems simple enough, a buoy which would fulfill all the stated operational requirements would be astonishingly sophisticated. Fortunately, a large part of the present needs are fairly well met by the Dan buoy (a brightly colored balsa and canvas cone with a flag -- users must forage for their own line and anchor). We will call it a "simple" buoy. Simple buoys should be:

1. Easily seen and identified (in daylight). Buoys having different meanings should have distinctive shapes or markings

2. Compact (folding -- collapsible -- easily stowed)

3. Simple, rugged, reliable

4. Smooth with rounded edges which are not damaging to rubber boats, suits, etc. (this is an even more important requirement for buoy anchors)

5. Plentiful (i.e., cheap)

6. Non-dragging. After being planted, they should not shift position because of currents, waves or wind. This depends partly on effective anchor design, partly on low drag resistance of the buoy and line.

The first stage of complexity adds the requirements that the buoy be:

7. Visible at all times (have light that will last 72 hours and perhaps a radar reflector)

8. Unsinkable by small arms fire -- and misguided landing craft

9. Depth taking. This means that buoy, line and anchor are a unit. When put overside, the unit sinks; a mechanism must release just enough line to allow the buoy to float directly over the anchor. This requirement would be fairly easy to meet if there were no tidal change. However, a delicate balance is required to allow a buoy to rise with tide but not drag out line in current.

The necessity for swimmers to operate rapidly and secretly in time of war, particularly to mark boat lanes some time in advance of an amphibious assault, adds the requirement for a buoy which also

10. has time delay mechanism so that it will rise to the surface at a pre-set time (such as H-hour). This time delay requirement is more difficult than is apparent at first glance, principally because these buoys are likely to be used on sandy bottoms;

the sand may shift to cover the mechanism or a single grain may lodge in such a place as to arrest its operation. Buoys of this type may be called "lighted, depth taking, time-delay complex" buoys. Two models have reached semi-production; the Hum and the Brock. These are expensive, and consequently few are available, and they are not very reliable. The price of a buoy may be insignificant in comparison with its value in an operation and the loss of a single LCVP because of buoy failure would pay for a large number of well designed buoys.

Thus development of both simple and complex buoys which are more usable than the present models is desirable. No research is needed as a prerequisite for this development because the basic information is well known. The work should be put in the hands of men who understand not only mechanics, but also the sea, and swimmer problems. Categorical instructions to such a group, as to shape, material, or even performance would probably not reap the best results. It would seem best to work first on a completely satisfactory simple buoy; then on a lighted, depth-taking buoy and finally on a time-delay buoy. The first two buoys are likely to be of general use throughout the Navy; the latter will probably be most successful if custom-made to solve a particular problem. The design of buoy anchors suitable for use from small craft should go hand-in-hand with design of the buoy itself. In many instances locally made cement blocks or locally found scrap (such as a large chain link, which has the advantage that it will not tear a rubber boat) make a perfectly satisfactory anchor. But such scavenging should not be relied upon. Anchors should be furnished with each buoy -- at least in a two to one ratio since they are rather easily lost when the buoy is retrieved after use. New buoy designs can probably make profitable use of new materials -- plastic foam, self-sealing bags, [illegible] concrete, honeycomb, reflector surfaces, fluorescent paint, nylon line, etc.

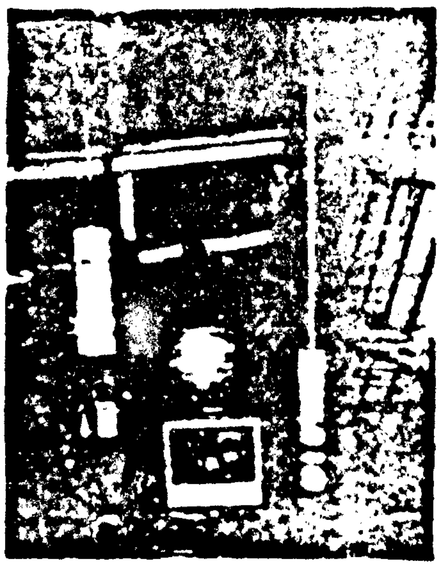

Fig. 7 Typical Buoys for underwater swimmer use. (l-r) Brock, Hum, and [illegible]

13.02 Conclusions and Recommendations

1. Buoys are an important item of an underwater swimmer's equipment because they translate his detailed knowledge of underwater conditions into terms suitable for surface forces. It is conceivable that the success of a large operation might hinge on the successful use of buoys by underwater swimmers. Present simple buoys for daytime use are reasonably satisfactory but there is need for lighted, depth-taking, time-delay, "complex" buoys and their associated anchors.

2. Development of complex buoys, preferably tailor-made for specific types of operations, should be continued. Use of new materials such as plastic foam, self-sealing bags, washtub concrete, honeycomb, reflector surfaces, fluorescent paint and nylon line, etc., should be investigated in this development.

14.00 DEMOLITION AND ORDNANCE EQUIPMENT*

Demolition explosives are the chief offensive weapon of UDT's. Existing high explosives appear adequate for demolition missions in accordance with present UDT doctrine and improved explosives are becoming available to UDT's as they are developed. During pre-assault operations it is customary for the swimmers either to tow the explosives to the target, or to transport them in their rubber boat and LCPR's.

Flexibility and early secrecy of swimmer operations could be maintained if explosives could be transported while the explosives and the swimmer were completely submerged. A towable explosive container has recently been tested which maintains its depth and trim automatically while being loaded or unloaded. This is definitely a step in the right direction though it is still necessary to make explosives which fit the container. Explosive packs should be streamlined, standardized and built to be towed individually or in series. It is also conceivable that a submerged swimmer may on occasion have to tow Mark 8 demolition hose for channel blasting, or limpet mines for sneak attack.

Attention should also be directed to means for stowing explosives while transporting them, and to means of maintaining neutral buoyancy while submerged.

14.01 Conclusion and Recommendations

1. Demolition explosives for UDT use under current doctrine are satisfactory and means of submerged towing of explosive charges are under test.

2. World War II U. S. and foreign limpet and sneak attack ordnance designs are available. As sneak attack and antishipping techniques are developed it will be necessary to concurrently develop the required demolition and ordnance equipment.

* This subject was not pursued in detail by the authors so only their preliminary findings are recorded here.

15.00 MISCELLANEOUS EQUIPMENT

In addition to the equipment mentioned in previous chapters, swimmers need many items of equipment to aid them in reaching their objectives and in carrying out their assigned tasks. The following notes outline the present status of some of these items.

15.01 Face Masks

Personal preference, often based on facial contours, is the overriding consideration in the selection of a mask. For this reason, it is unlikely that any one type of mask will be acceptable to all of a large group of underwater swimmers. Some men like a hard rubber mask which seals by penetrating the skin; others like the soft edge which is held against the face by water pressure. The swimmer will be annoyed if the mask is not rigid enough to hold the glass away from his nose at depth. The Voit (Senior B-2) made of a medium hard rubber with a round lens, and the Champion, a soft edged rubber mask with an oval lens, seem to be most generally preferred.

Most masks have the disadvantage of limiting the swimmer's field of vision to the order of 90-100°. Some development effort should be directed towards reducing this deficiency.

15.02 Life Preservers

The newly issued UDT life preserver seems to fulfill the requirements very well. It is light, takes up little space and is quickly inflatable from a single CO_2 cylinder. In use it supports the wearer's head above the water quite comfortably. An underwater swimmer in trouble can quickly surface by simply pulling the CO_2 release cord. It might be desirable to integrate a life preserver with SCUBA.

15.03 Watches

In military operations a watch is an extremely important item of swimmer equipment for often his life depends upon being picked up at a certain time prior to demolition explosion. It is also very important to all underwater swimmers when diving in depths requiring decompression. To date no watch is available to the underwater swimmer which is completely satisfactory. The usual difficulty is that the case leaks; this of course ruins the watch. It is suggested that the technique used by oceanographers to send delicate mechanisms to great depths be tried; namely of filling the case with light mineral oil or other fluid. This makes it necessary to change the escapement slightly but in no way impairs the accuracy or use of the watch. A simple "O"-ring seal will prevent leaking in either direction since there is no pressure gradient. A suitable watch should be:

1. Readable in the dark and in turbid water.

2. Non-magnetic.

3. Shock-proof.

15.04 Knives

"A swimmer's best friend is his knife." This simple and essential piece of gear still meets with some criticism in its present form. The blade (some 6" long) needs to be more rust-resistant than are the present models. The case should be of plastic (rather than leather) and have an integral spring clip to hold the knife firmly in its sheath. It must be remembered that the user may be unable to see, may be shivering, may have gloves on, and may be in a great hurry. A proposed design which looks satisfactory but is still in blueprint form, has one saw-toothed edge, a roughened grip handle, and is non-magnetic.

15.05 Compass

Navigation underwater is difficult, as anyone who has tried to swim in a straight line without reference points will testify. In turbid or dark water, particularly away from the bottom, a man very quickly becomes lost. A workable compass is one obvious means of minimizing this problem, because compasses have the same characteristics below as above water. If a magnetic compass is to give accurate performance the diver should not carry large quantities of magnetic materials. (Aqualung bottles, for example, may seriously influence a compass.) A compass should be small, sturdy, and have a luminous dial; it should be operable at depths up to 200 feet and when inclined as much as 30°.

The depth requirement is easily solved -- by filling the case completely with a liquid; the requirement that other swimmer gear be largely non-magnetic waits on other developments. Fraesotto [22] has suggested that a compass should be attachable to the wearer's face mask as well as to his wrist; this would greatly facilitate following a course. A suitable non-magnetic fitting which would hold the compass out of the principal line of vision, is necessary.

15.06 Swim Fins

Like other mammals, man can be expected to maintain an output of about 0.02 HP per pound of muscle for a number of hours. In equipping a man to move about underwater, the problem is to use this available muscular energy in the most efficient possible manner. Swim fins have made the most improvement in the energy transmission to date.

Fin efficiency is obviously dependent to a large extent on the nature of the swimmer's kick and the following remarks concern a trained endurance swimmer skilled in using a flutter kick at the rate of two to four kicks per breath. Like other hydraulic mechanisms, fins become more efficient as more water is handled; consequently, they should have as much surface area as possible for the power available. Fraesotto, [6] in experiments at Little Creek, has found a rather large variation in the efficiency of the various commercial types of fins. By comparing six kinds of fins, he ascertained that the speed increases with the length and hardness of the rubber and the comfort increases with the pliability of the rubber.

The two brands of fins which seemed to have the best all around characteristics were the "Duck Feet" (manufactured by Spearfisherman, Laguna Beach, California) and the "Swim Fins" (green, medium pliable, manufactured by Owen Churchill, Los Angeles, California). Quite possibly an improved fin could be built which would have a soft, pliable rubber around the foot becoming less compliant towards the tip. One would not expect to make major gains in efficiency by developing such a fin however, because of unpredictable individual preferences.

15.07 Depth Gauges

Both in swimming and in controlling decompression, underwater swimmers very often need to know their depth below the surface. Two systems for measuring depth (pressure) are used: the bourdon tube and the manometer, and several depth gauges of each type have been built. These are satisfactory for operations in daylight to 100 feet and there seems to be no obvious reason why one type should be better than the other. The gauge now being procured for UDT use (from U. S. Gage Co.) seems to be quite satisfactory to 100 feet. However, the military requirement that the gauge be readable at night and the fact that scientific swimmers would like to know depths to 250 feet adds to the design problem.

In many operations underwater swimmers must frequently and unpredictably change depth. In such a complicated situation, use of the diving tables for optimum control of decompression time becomes very difficult. Munk and Groves [*] have suggested that a simple "analog computer" gauge might be built and worn on the swimmer's suit or body. They point out that a system of sylphon bellows connected by capillary tubes would be analogous to the flow of nitrogen between the lungs, the blood stream and the body tissues. At the surface all bellows would be at the ambient pressure; as the swimmer descended, the change in pressure would cause flow through a capillary into an inner chamber comparable to the passage of nitrogen from the blood into the tissues. A diaphragm would be linked to a needle and the differential pressure read on a dial. As the diver ascended, his problem of decompression would be solved by keeping the differential pressure below some designated danger line.

15.08 Surveying Devices

Present beach reconnaissance techniques for inshore underwater surveys involve the use of a line-carrying flutterboard for measuring distances and a light lead-line for measuring depths. Depth-distance data are recorded by the swimmer on a tablet; on shipboard this is translated into a beach profile. These devices have been reasonably satisfactory for surface swimmers but increasing requirements for operational secrecy may make it necessary to use new methods.

It seems quite feasible to build a device that would plot distance against depth (make a profile) while being moved about by an underwater swimmer. This would have three advantages: 1) no preparation (such as securing a line ashore) would be required and the instrument could be used for spot check anywhere; 2) profiling would be continuous rather than intermittent; 3) transfer of profile to final sheet could be done directly. One way of making such an instrument would be to

*Part I, Appendix A, pg. 10

have a pressure-actuated diaphram move a scratch-stylus across a film which is moved in some ratio with the distance traveled along the bottom.

For making inshore hydrographic studies where less secrecy is required and more area need be covered, a small recording or telemetering echo-sounder could be specifically adapted to swimmer use. In addition to the depth, the position of the echo-sounder also needs to be recorded continuously; this may involve radar or sonar tracking from a parent craft, or a self contained location system operated by the swimmer, using known reference points on the beach.

Since one of the primary jobs of UDT's is beach surveying, it would seem that the development of such devices would materially increase the efficiency of the teams and is therefore warranted.

15.09 Trafficability Measuring Gear

It is highly desirable for an amphibious commander to know something about the trafficability of a landing beach and it is customary to ask reconnaissance swimmers to bring back this information. No simple gear is available which can be used to make a direct, meaningful measurement nor is there likely to be. The reasons are: 1) beach bearing-shear strengths change rapidly -- with wave changes and tide changes; 2) the trafficability varies considerably both laterally and longitudinally on the beach; 3) it is generally poorest above the high water mark (beyond usual UDT examination); 4) regardless of the original situation, beach trafficability changes when subjected to shell fire and transit by vehicles.

For test purposes with uncontested conditions the "soil truss" and the "cone penetrometer" have been useful. For UDT operations, a more valid answer might be obtained by training which would familiarize the men with the reaction of different types of beach to vehicle passage. (Refer to 04.32)

15.10 Conclusions and Recommendations

1. Face masks, life preservers, swim fins, depth gauges and knives now used by underwater swimmers, or becoming available to them, are reasonably satisfactory. Some improvements or changes may be desirable. The field of vision through masks needs to be widened; life preservers might profitably be integrated with SCUBA; swim fins with soft, pliable rubber around the foot, becoming less compliant toward the tip, might result in increased swimming efficiency. The depth range and night readability of depth gauges could be improved; and a new knife now in the preliminary design stage appears superior to the type currently used.

2. Watches, compasses, and bottom surveying equipment need considerable improvement. Most present swimmer watches leak when subjected to hydrostatic pressure.

3. A small, sturdy, luminous-dial compass, operable to depths up to 100 feet and when inclined as much as 30°, and rigidly attached to the swimmer's

face mask where he can watch it continuously when necessary, is needed to aid swimmer navigation.

4. Development of self-recording devices for measuring bottom depth and distances would increase the speed and accuracy of swimmer reconnaissance.

5. Both mechanical and acoustic methods of automatic bottom surveying should be investigated.

6. Underwater swimmers change depth frequently and unexpectedly. An "analog Computer" type of depth gauge which would simulate the interchange of inert gases between the blood and the tissues might greatly aid in controlling decompression to avoid the damage of bends and allow maximum time submerged. Research and development leading to an analog computer type of depth gauge should be initiated.

7. Development of devices for measuring beach trafficability is not warranted because the sampling errors would be too large. Instead, UDT's should receive more training in estimating beach trafficability.

16.00 COUNTERMEASURES

The objective of countermeasures against underwater swimmers is to prevent enemy underwater attackers from accomplishing their missions. Protection must be considered for harbors, bridges and river crossings, landing beaches and ships at anchor. Countermeasures to protect ships against underwater swimmers have been practiced in simple form, but there has been little systematic research and development in this field.

A most effective countermeasure is to prevent the parent submarine or airplane transporting underwater swimmers from approaching close enough to the objective to launch its underwater men. This is part of the general problem of antisubmarine warfare and air defense and will not be discussed herein, nor will we consider questions of detection and destruction of small submerged craft. These are an integral part of the harbor defense problem, which is being intensively investigated by the Office of Naval Research, the Navy Electronics Laboratory, the Operational Development Force, and other Navy activities. Similarly, protection against underwater swimmer saboteurs and Fifth Columnists, by preventing their access to beaches or harbor installations, will not be discussed.

Given the above limitations, the problem of underwater swimmer countermeasures can be divided into problems of detection, location, identification, deterrence, and destruction.

16.01 Detection

Surface detection. Detection is used in the broad sense of being aware of the presence of a swimmer-like object. Three principal methods appear to be available for detection above the water surface: visual, radar, and infrared.

In the daytime a submerged swimmer using open circuit breathing apparatus may be detected by his bubble trail. At night, he may produce some phosphorescence in the water which can be detected on the surface. When the swimmer emerges, his head can be seen in the daytime although camouflage, rough sea conditions and the slow motion of swimmers all reduce the effectiveness of the human eye in detection. At night artificial illumination greatly aids the sense of vision, particularly if the swimmer can be silhouetted by a light from the side or in the rear. In general, men who have had experience in visual swimmer detection state that parachute flares or bright moonlight are preferable to searchlights.

Radar can be used for detection at greater ranges than human vision but is not as effective at short range. In recent tests, using an MPC harbor defense radar at an elevation of 125 feet, heads of swimmers were detected at 2450 yards with a 15% time of echo on the oscilloscope. Forty per cent time of echo on the oscilloscope was obtained at about 1,000 yards (for swimmers without artificial propulsion this is 30 minutes away) Because of sea clutter, the minimum range was about 500 yards.

No information is available on the use of infrared for detection of swimmers' heads above the surface, but this would appear practical as a supplement to the unaided human eye, particularly at night. The Navy Electronics Laboratory is planning tests of infrared in the near future.

Subsurface detection. Radar and infrared cannot be used for detecting submerged swimmers. The range of visual detection is also limited. Underwater sound detection by listening would appear to be relatively ineffective but echo ranging gives promise.

The high turbidity of harbor waters greatly limits the range of underwater detection. Not only is the range at which an object can be seen, even with full illumination, reduced, but daylight cannot penetrate far below the surface because the light is scattered and absorbed. Artificial illumination below the surface somewhat mitigates the situation, particularly if the object to be detected is between the light source and the observer, because there is then only a one-way optical path. It might be supposed that the range of visibility might be increased by a very powerful light source, but this is not true because the range of detection is limited by scattering rather than by absorption of the light. Because of the short range of visibility in harbor waters, the observing eye must be relatively close to the object to be detected. Television or underwater periscopes (hydroscopes) may be of value in this way.

Although swimmers using open circuit underwater breathing apparatus produce some noise because of the air passing through the valves and air lines, preliminary tests indicate that in locations of average background noise the range of listening detection is only about 15 feet. With closed circuit apparatus, the range of detection will be much smaller.

The possible range of detection for sonar echo ranging appears to be greater than for any other means. Tests under the cognizance of the Panel have indicated

that an underwater swimmer using self containing underwater breathing apparatus has a sonar target strength about equal to that of a moored sea mine. Mine hunting experience with sonar suggests, therefore, that swimmers may be detected with sonar at ranges of several hundred yards under good conditions. Doppler effects resulting from the swimmer's motion may enhance the range still more. On the other hand, a swimmer moving very close to the surface or very near the bottom may be concealed by surface or bottom reverberations.

Present self contained underwater breathing apparatus is somewhat magnetic and magnetic detection equipment may be expected to be effective at ranges of a few feet. Even this detection range would be eliminated with SCUBA's built of non-magnetic material.

Hydrostatic pressure changes due to the motion of the swimmers through the water might be supposed to be useful. But recent tests indicate that these changes are less than one-tenth of an inch of water even when the swimmer is quite close to the pressure element and this small signal will generally be below the background of surface waves.

Underwater electric potential (UEP) equipment may be able to detect swimmers at short ranges, not only because of the currents produced by different metals in the swimmer's equipment in contact with sea water, but also because of the difference in electrical properties between the swimmer and his equipment and the surrounding sea water.

Contact detection equipments attached to underwater barriers or structures, for example trip wires, have been used as detection expedients, but there is little quantitative evidence on their effectiveness.

Intelligent marine mammals of the seal family might possibly be trained in the detection of underwater men, just as dogs have been used for night detection on land. That these animals can be trained is well known, but little information is available to the Panel on their psychology; for example, their tendency to become bored.

16.02 Location

Location is the process of fixing the exact location of the detected object. For objects on the surface, bearing can be obtained by visual, infrared, or radar means. The great advantage of radar is the accurate range which it gives. Location under water can be only approximately accomplished by visual, magnetic, underwater electric propagation, or mechanical means primarily because of the very short detection range of these methods. Sonar, in addition to its longer detection range, also has the great advantage of giving accurate location.

16.03 Identification

Identification is the process of determining that the object detected and localized is actually a swimmer. After an underwater object has been detected

it must be determined whether it is a fish, underwater mammal, inanimate debris, submerged craft, or an underwater swimmer. Identification also requires that distinction be made between friend or foe.

On the surface, identification can be made visually or by some types of infrared equipment. Radar identification is relatively unsatisfactory. Under water, vision is the only reliable means of identification and it is therefore necessary to supplement other detection means by the ability to actually see the object. Underwater television might be useful for this. Perhaps future research might uncover a sonar or UEP signal that is characteristic of underwater swimmers.

TABLE V

SUMMARY OF SWIMMER HUNTING METHODS*

	DETECTION	LOCATION	IDENTIFICATION
VISUAL	Fair [Good]	Fair [Good]	Good [Good]
RADAR	Poor [Excellent]	Poor [Excellent]	Poor [Poor]
INFRARED	Poor [Unknown]	Poor [Fair]	Poor [Fair]
SONAR LISTENING	Poor	Poor	Poor
SONAR ECHO RANGING	Good	Good	Poor
MAGNETIC	Poor	Fair	Fair
U E P	Poor	Fair	Poor
HYDROSTATIC PRESSURE	Poor	Poor	Poor
MECHANICAL (direct contact)	Needs Test	Needs Test	Poor

* Items in table refer to submerged swimmers.
[ ] Items in brackets refer to surfaced swimmers where method is applicable.

16.04 Deterrence and Destruction

Deterrence, diversion, or destruction, of an attacker is the ultimate aim of countermeasures. The most successful method employed to date against underwater swimmers has been use of random placed and timed small explosive charges. The major limitation of this method is the logistic one imposed by the requirement for large amounts of explosives. The effect on friendly installations must also be considered. If the underwater enemy has been detected and located, however, depth charges or explosive projectiles can be economically employed.

Underwater nets have been used in various ways to deter underwater swimmers. Present-day nets are extremely heavy and bulky, and are easily cut, raised, passed over or under, or dropped to the bottom. Nets in rivers are subject to particularly heavy stresses from current action and from debris in the stream. These limitations suggest the use of underwater barbed wire or the erection of semi-permanent obstructions such as wires, causeways and sheet piling. Barbed wire can be easily and quickly installed but other obstacles require time and effort for installation.

Counter-swimmers have been suggested to destroy the attacker. Underwater movements are slow and cumbersome and not suited to physical struggle. But the use of underwater weapons such as gas or spring-driven spears is feasible. The short range of visibility in most harbors is a serious limitation for counter-swimmers. While the effectiveness of underwater man-to-man combat as a defense against swimmers may be doubtful, underwater swimmers may still be used effectively in searching at regular intervals for limpets or other placed charges.

It has been suggested that the brain, sense of balance, ears or abdominal organs of underwater men may be vulnerable to high intensity underwater sound, either sonic or supersonic. This has been superficially investigated as a means of deterrence, but little quantitative information is available. It should be possible to obtain some of the needed data with acoustic mine sweeping gear.

Strong alternating electric currents are used to deter fish from entering wiers and underwater orifices; their use may have some applicability against swimmers who are unprotected by insulating suits.

Trained mammals have been discussed under Detection. If they can be trained to detect, they might be trained to press home an attack or to approach with explosives, probably at the expense of self-destruction.

Because the velocity, relative to the water, of an unaided underwater swimmer is only about one knot, rapid water motion around the object to be protected may be an effective deterrent. For example, a ship's screws may be reversed to wash swimmers away from the hull, or the ship may be kept in motion at low speed.

In addition to its use in detection, artificial illumination can be employed as a psychological deterrent. Care must be taken to avoid unnecessary disclosure of friendly installations.

It is relatively easy to increase the turbidity of the water and this may in circumstances when the underwater men must remain submerged, an effective deterrent. Selection of operational sites where the water is turbid or where strong currents exist will usually be advantageous to the defender.

Patrol craft may be utilised in detection, and they may also be used to sweep the underwater area by towing nets, hooks, or chains. They will be indispensable as an adjunct to other methods of destruction or deterrence.

TABLE VI

SUMMARY OF DETERRENCE AND DESTRUCTION METHODS*

	DETERRENCE	DESTRUCTION
SMALL ARMS	Poor [Excellent]	Poor [Excellent]
UNDERWATER EXPLOSION	Poor	Excellent
STRONG CURRENTS	Excellent	Poor
COUNTER SWIMMERS	Unknown	Unknown
HIGH TURBIDITY	Good	
HIGH INTENSITY NOISE	Unknown	Unknown
NETS AND OBSTACLES	Fair	Fair if combined with automatic weapons
ARTIFICIAL ILLUMINATION	Fair [Good]	

* Items in table refer to submerged swimmer.
[ ]Items in brackets refer to surfaced swimmers where method is applicable.

16.05 Conclusions and Recommendations

1. Countermeasures against underwater swimmers have been practiced in simple form but U. S. forces do not have available the knowledge to mount a round-the-clock defense of harbors and anchored fleet elements against a group of determined swimmers. The need exists for intensified systematic research and development in this field.

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